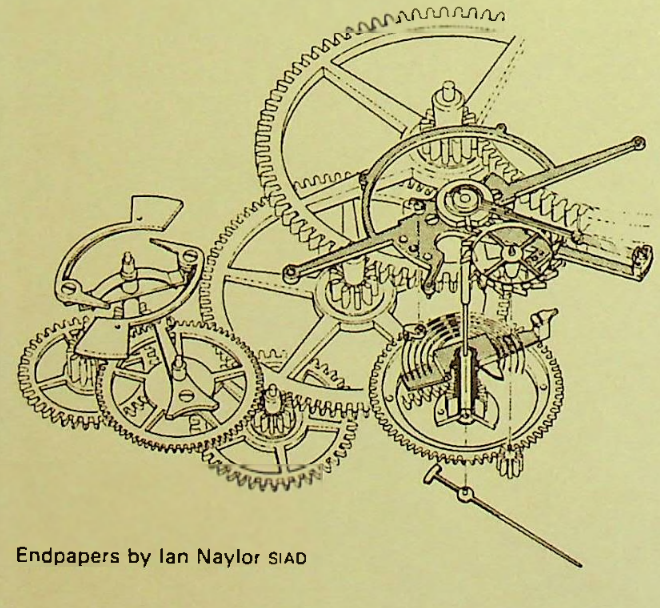
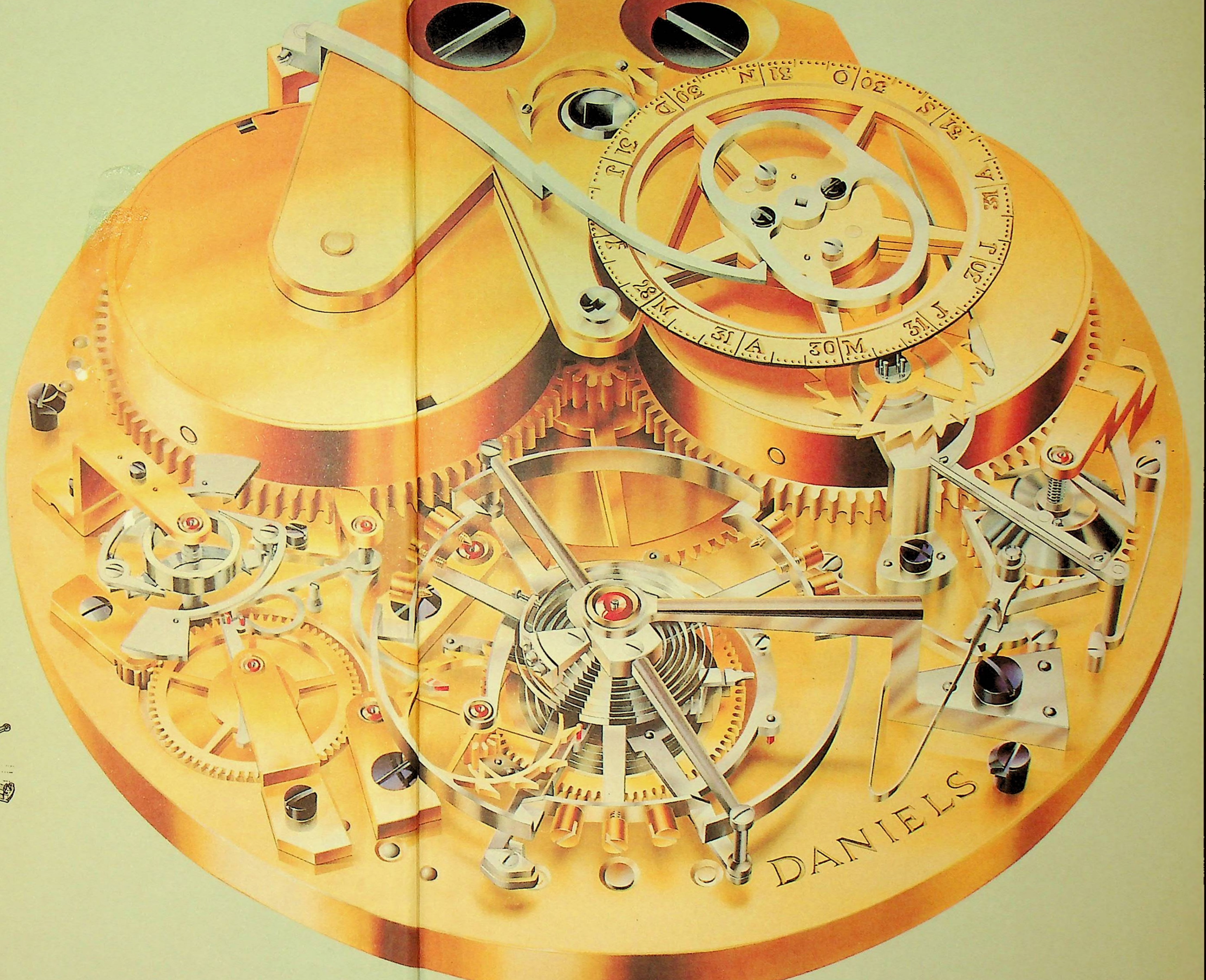


Endpapers by Ian Naylor SIAD

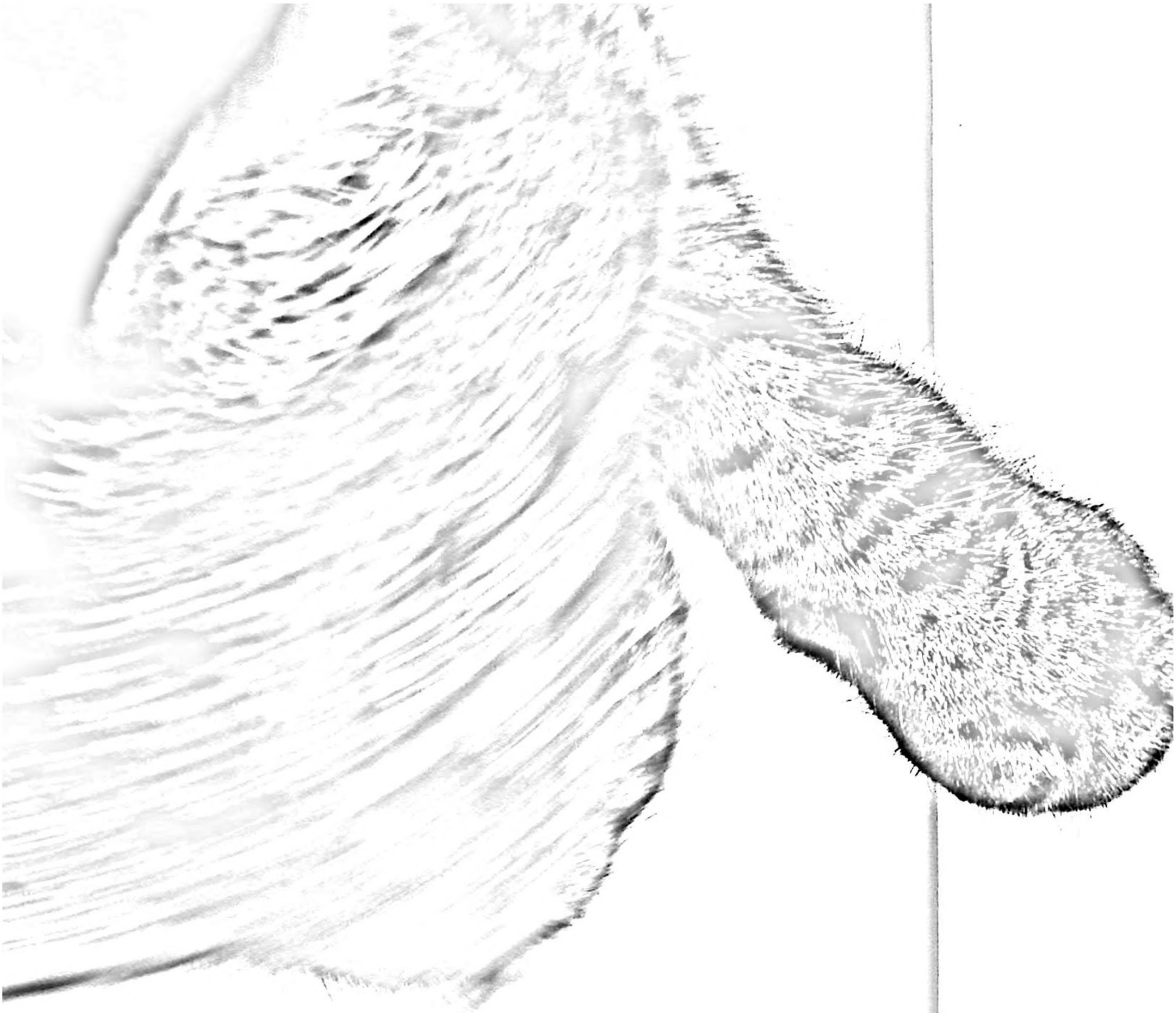


GEORGE DANIELS

WATCHMAKING

Drawings by David Penney
Photographs and additional drawings by the author

Philip Wilson



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ACKNOWLEDGEMENTS

It is fifty years since I attended evening classes at the old Northampton Polytechnic in Clerkenwell, but I remember with clarity and affection Mr H. F. Harrison who was the principal horological instructor. He helped me to an understanding of the theoretical principles of horology that encouraged the interpretation described in this book. He was unanimously appreciated by his students and it is my privilege to offer thanks for his kindly and patient insistence that we worked towards a sound knowledge of our subject.

My thanks are due also to my friend Dr Andrew Lumsden who has no experience of watchmaking but who read the manuscript and declared his understanding of it, so that I am led to believe that the book may be useful to beginners.

My friend Cecil Clutton deserves mention for he bravely bought my first watch and by doing so proved my view that there is a future for makers of hand-made watches. He has, thus, also encouraged the necessity for the book so that others may prosper.

Thanks are due also to Elizabeth Wiltshire for her meticulous preparation of the text, to Rodney Law for kindly undertaking the chore of verifying the arithmetical equations and annotations, and to Janet Dudley for compiling the index.

Finally, thanks are due to my publishers for the care they have taken with the production of the book and for their consideration of my views on the design and format.

PREFACE TO THE THIRD EDITION

Since *Watchmaking* was first published in 1981, many changes have occurred within the industry to enhance the interest and value of the handmade watch. Even the most pessimistic no longer believe that the quartz watch will bring about the end of the mechanical watch. In fact, the mechanical watch has fully recovered its importance in the industry and is in ever-increasing production.

This shift has been caused by the rising cost of manufacturing new designs, which has lead the majority of makers, both old and new, to buy-in their components and sometimes whole movements. Inevitably, these watches are therefore becoming more and more uniform in movement design, a situation that has turned the attention of some makers towards the manufacture of very complicated mechanisms. These expensive watches are made in series, with the result that they are not individually recognisable and accordingly, less desirable to the connoisseur collector.

Thus, the hand-crafted, individually designed watch is increasingly attractive to those who appreciate the historic, technical, intellectual, aesthetic, amusing and useful qualities of a tiny machine that must also serve a practical purpose throughout the day.

That *Watchmaking* has been successful in its aim to assist and encourage aspiring watchmakers is evident from the correspondence and testimony of its readers. This edition is the third English version, following the French edition, from which the new watches and revisions are included here. In addition, the colour plates show both pocket watches and wrist watches with keyless winding. I do not like the large winding crowns that dominate the English watches and have, in the past, preferred to wind with a key. The system now used allows winding and handsetting by use of a three-position pendant that is locked stationary into the case. One pull up releases the pendant to be used as a winding key, while a second pull up allows for handsetting. Pushing the pendant back into the case secures it for general use in the pocket. The winding crowns of the wrist watches are unconventionally placed so as to present a smooth, uncluttered surface. A wrist watch of half the diameter of a pocket watch has only one quarter of the area. Because they need to be sealed against ingress of moisture they are not so easily opened for examination. A sapphire window in the back of the case will assist in viewing the movement.

Care in the design of the wrist watch is necessary if the dial is not to resemble a gas-meter – as the cluttered faces of so many modern watches do. Of the three examples illustrated, Plate XXII is a simple self-winding movement with calendar and centre seconds. To use a subsidiary seconds dial in addition to the calendar ring would reduce the clarity of information. Plate 1 includes a *tourbillon* and chronograph mechanism with subsidiary chronograph dial and concentric minute counter. The mechanism, designed to fit into unused space, prevents both increase in the thickness of the movement and domination of the dial. Plate XV avoids crowding the face by use of a reverse dial for the calendar. Pressure on the button at the 8 o'clock position will release the inner case to open and reveal the reverse dial without removing the watch from the wrist.

These are offered as examples of variation from conventional designs that enhance interest in the watch while maintaining its integrity of design. Students sometimes introduce style for its own sake in an attempt to distinguish their work. Such artificial attraction soon becomes dated and holds little interest for the collectors and patrons of the artist-craftsman's work.

The chapter on escapements has been completely revised to emphasise the merit of escapements with reduced friction. The form of impulse of the lever escapement has sustained the watch for 250 years but, if improved performance in both the short and long term is to be achieved, then new forms of escapement with less friction are needed. A detailed description of the design and geometric arrangement of the co-axial escapement, together with new drawings, is included. This escapement, by reason of its constancy of balance amplitude, can maintain a close rate of timekeeping for many years without need of maintenance. It is not offered as a final solution to the watch escapement but, more particularly, as an incentive for future watchmakers to develop further the mechanical watch.

It is now thirty years since the first Daniels watch was made and sold. It was produced as a public rejection of the then-popular view that the quartz watch would supersede the mechanical watch. I have never been in any doubt that it could not. The following years have been spent in making a variety of watches, some of which are illustrated here. There is no more satisfying career than that of the artist-craftsman horologist, and I can wholeheartedly recommend it to readers. If this book assists others to succeed in watchmaking in future years, my satisfaction will be all the greater.

George Daniels
Riversdale, 1998.

PREFACE

During the past ten years many people have written to me to express their wish to learn to make watches. While it has not always been possible for me to give practical help, our discussions have been very useful for they have enabled me to assess what kind of information would be most useful to them. My conclusions are contained in this book.

Watchmaking in England emerged as an industry in about 1600. The style and design of the watch mechanism were imported from the Continent, watchmaking having begun there in Germany and then taken up and improved upon in France. In England the industry grew, with little technical change, until the introduction of the balance spring in the late seventeenth century. However, the improvement resulting from this invention was not enough to make the watch useful for any other than simple, civil use.

It was not until the mid-eighteenth century that the watch was capable of maintaining a rate of timekeeping that entitled it to be described as a 'timekeeper'. This was a period of intense scientific discovery in Britain and the inventors of the precision timekeeper played an important part. They not only discovered the scientific principles necessary for designing a timekeeper, but they also helped the development of other branches of the sciences by the use of their timekeepers. Harrison, Mudge, Arnold and Earnshaw are men whose names are essential to the story of the invention and development of the portable precision timekeeper. (Full descriptions of their work are included in publications listed in the bibliography.) The combination of their inventions, and the quantity production of the resultant timekeepers, gave Britain a commanding lead in the science and manufacture of watches.

Expansion of the Swiss watchmaking industry in the first half of the nineteenth century saw the beginning of the decline of the industry in Britain. The Swiss industry thrived on mass-production techniques which enabled the production of cheap watches of adequate quality for everyday use. The change in economic climate, allowing the Swiss to succeed with quantity production, also reduced the market for expensive hand-finished watches which, by the late 1920s, could not support an antiquated industry. The industry finally ceased in England in the 1930s.

My own interest in watches goes back to my earliest recollections of independent activity, but it was not until 1967 that the prospect of making watches again in London became irresistible to me. As a result of restoring the work of other watchmakers for many years I had acquired some useful workshop knowledge, a good variety of hand tools and some antiquated making and finishing tools. These included a brass mandrel, a topping tool with sufficient cutters to be useful and an 8 mm lathe with some accessories. In addition there were two engine-turning machines, one a rose engine and the other a straight line engine, both given to me by the late Professor David Torrens.

Torrens had spent a lifetime at the benches of surviving practitioners studying the methods of a bygone age of watchmaking. His generosity was boundless and, as his mentors died one by one, he paid their widows most generously for their tools which he stored away in his rooms at Trinity College, Dublin. He stored the knowledge that went with them in his head with the intention, one day, of committing it to paper. He retired at seventy ready to start writing a treatise on English watchmaking methods but within two weeks he died, taking his knowledge with him.

Torrens was a most kindly man who possessed a knowledge of everything that he had ever heard or read about in his obsession with horology. He had a vast library but never needed to refer to it for he could recollect with ease not only the contents of the books, in three languages, but could also quote from them page and line. I had visited him in Dublin to collect some of the parts of the engine-turning machines and talked for hours about watchmaking methods. It became increasingly clear to me that it was not the practice for one man to make the whole watch by himself. Over the centuries, it had become established that the simplest way to make watches was for the work to be divided into distinctive and entirely separate trades.

When I returned to England with the parts for the rose engine, I thought over what I had learned in Dublin. The tools that Torrens had collected consisted for the most part of simple pieces of equipment of amateurish construction and with the neglected appearance of years of disuse. The most significant aspect of his monumental store was that, for the most part, the purpose was unrecognizable and, where it was, there were few remaining traces of the method of use.

It was then that I realized that there was to be no rediscovery of the pleasure of watchmaking by traditional methods, and that such methods had no special merit anyway. The best contemporary methods would be the ones that succeeded by adaptation of existing equipment. Torrens had described his old watchmaking specialists as masters of the 'cork and nail' method. This was an over-simplification of their ability but it was true that their work was accomplished by the experience gained in making familiar components by the skilful manipulation of simple tools. That was the English method and it saw the rise and fall of an industry which finally ended with the death of Sidney Better in London in the mid-1930s.

In considering my own tools I felt that, with the addition of some improved means of cutting wheels and pinions, they would be sufficient for my purpose. I therefore bought a small, much used, Schaublin bench lathe for this and the general work of making the larger components. Two lessons were learned from this lathe. First, it is false economy to buy used lathes. They are usually sold because they are worn out. Secondly, worn machines can do good work but only if the operator learns to master their idiosyncrasies. This latter is reflected in the quality of work produced in the past on equipment that would today be considered extremely crude. I could afford to do no more than follow past example and persevere with the lathe. Thus equipped for work, the first watch was laid down on paper. The following two years were spent in experiment and practice to acquire an understanding of the technical requirements of a watch and to learn the techniques of its manufacture from the raw material.

Mr. A. T. Oliver, a casemaker of rare skill who at that time had a Dickensian workshop in Clerkenwell, agreed that for a sum of money I should have the privilege of making my first watchcase under his guidance. The work took five days to complete, after which the case went to the Assay Office to be hallmarked and subsequently my newly made name punch was registered. Thanks to Oliver, the last Clerkenwell casemaker, my apprenticeship and my first case were completed. He was not forthcoming with compliments but he did not criticize the work and, for a man steeped in the ways of old Clerkenwell, that was praise enough to encourage further work.

The intervening years have seen many watches completed and each one has included some feature that has brought an improvement in performance. This is a slow process for it takes many months of testing to be certain of the result. But it is an important aspect of the watch that the timekeeping must be at least as good as the best of the past and it is not unreasonable for the purchaser to expect it to be better, especially in the long term.

On a general level it is assumed that a complex array of tools is required but I have not found this to be so. It is true that since the completion of my first watch by very nearly, if not quite, 'cork and nail' methods, the equipment in my workshop has expanded to include precision measuring and machining equipment. Although they make working easier they are not strictly necessary. Such tools are expensive to buy and a young watchmaking student would not have the money to purchase them. I have made only passing reference to them in this book and nowhere is the work described dependent upon such equipment. Nevertheless, precision machinery can save time and reduce the amount of concentration necessary to make small components by hand methods. The student can acquire these as advancing years bring reduced patience and increased income, but it should be remembered that if he cannot do the work well without machinery he will not improve with its aid.

Because there are now no specialist manufacturers of components waiting to fulfil the ambitious watchmaker's demands he must now satisfy them himself. Only then can he avoid the delays that can occur in the completion of orders given to such specialists. By developing the skills required to make all the components of a watch, including the case, dial and hands, the watchmaker's programme is never influenced by the time-tables of outworkers. In addition workshop overheads and labour costs, even for the most commonplace work, are now so high that the independent watchmaker is at an advantage. When it is considered that a watchmaker can make only one good and individual watch in a year, and the watch cannot be sold until it is completed, it is not good economic sense to spend money on expensive work that must be paid for early in the watch's manufacture. It is this kind of economic factor that can cause a watchmaker's ambitions to fail. The only way to certain success is to become proficient in all the crafts represented in the complete watch and to work without regard to so-called conventional hours of work.

Considering the fascination that so many young men find in small mechanisms it is not surprising that many of them drift into the world of watches. Because there are so many millions of watches in need of service and repair, a comfortable living can be made without much effort. Watchmaking is more difficult but more satisfying, although it involves many more consecutive hours of concentration if the work is to be completed within a reasonable time. For example a *tourbillon* watch of the type illustrated on Plate IV would take some 3,000 hours for a competent beginner to make. At a rate of some seventy-five hours per week, about forty weeks would be required. This leaves twelve weeks to attend to all other contingencies of the year. If the watch is to be sold successfully the maker must be his own advocate and encourage a buyer. This can consume many hours of social intercourse, founded upon a sound knowledge of horology, so that the prospective buyer may fully understand the virtues of the watch and be sufficiently impressed to part with his money.

It would be alien to my own philosophy to over-emphasize the difficulties that can beset the ambitious watchmaker. These are for overcoming and he will do this in his own way. I do not want to put too much value on commercialism either, but it is a fact of life that one must be self-sufficient if one is to be seen to be successful, and to be seen to be successful is to enhance success. It is my belief that most of the world's finest works of art were made by professionals for money and, if this is not absolutely true, then it is generally so.

The watch must be original in design and conception and, when completed, beautiful in appearance. Only then will it attract a buyer. Connoisseurs of watches are not interested in copies of other makers' work. They do not buy watches simply because they have need of them but because they are excited by them and this excitement must be engendered by the maker. To advise a student to acquire all the different skills required to make a watch and then to insist that it has some attractive quality that makes it saleable may sound like a tall order. I myself, as a student in 1950, would certainly have thought so. I did not believe it could be done until much later when, in 1969, my first watch was completed. It is difficult now to understand why there should have been any real doubt unless it was that, as a student, I was taught the theory of watches and how to recognize tools, but was not encouraged to believe that this knowledge had any creative future. The art of watchmaking was dead; there were no watchmakers and therefore there was no one to teach it.

The active watchmakers' schools in Switzerland taught the technical aspects of horology and, until recent years, students were expected to complete an *ébauche* movement for a watch. The principal aim of the schools was to provide young technicians for watch factories where they would, presumably, continue the custom of producing endless numbers of uniform watches for sale in retail shops. The best of the students that I knew saw no future in this for their new and complex knowledge and drifted into other branches of the trade which, although more lucrative, were less interesting. In fairness it must be said that the Swiss were not alone in believing there was no other market. And if they did not believe that one existed they can be excused for not encouraging their students to exploit it. But it was my firm belief that there were people with a different interest in horology who would one day encourage a fresh start by purchasing individual and hand-made watches.

My principal interest has centred upon the development of the watch as a precision timepiece independent of electricity. This process had started effectively in London and I could see no reason why it should not continue there. The prospect was enhanced by a resurgence of interest in the mechanical watch encouraged, I believe, by the advent of the wholly commercially orientated, electronic watch. As a result it would be possible, once again, to make watches in London.

It is in the belief that a younger generation can now be encouraged to find a future in watchmaking that I have written this book. It was my intention to write it when I had learned enough to make its writing worth while. But the start of the work was precipitated by two weeks' uninterrupted rainfall in the little hamlet of Cold Cotes deep in north Yorkshire, where my family and I spend holidays. There one can write for many days without interruption or the distraction of fine weather. An additional encouragement for me to begin was the need to help satisfy the thirst for knowledge of the many students who write so charmingly to seek admission to my workshop. Regretfully this is rarely possible but if this book helps them to discover their own talents it will have been more useful than a brief visit. Perhaps if I had waited longer before starting I might have found better methods of executing the work described. But I need make no apology, for all can be accomplished on simple equipment and I have found all to work satisfactorily.

Watchmaking is not a finite subject, for the watch is open to continuous development and is the vehicle for many additional complications. My principal interest has been in the making and development of the precision watch and this forms the basis of the contents of this book. It covers all relevant aspects of the precision elements of the watch and, as a general guide, details of construction and essential dimensions are given for a *tourbillon* watch.

Observing students at work and talking to them about their results has shown that they are quite capable of producing good, original work once they are sure there are no secret methods without knowledge of which success is uncertain. Often one hears the amateur criticize the professional for guarding his secrets and thereby retarding the student's progress. But there are no secrets in watchmaking. The methods are simple and commonplace and can be acquired with intelligent practice. When a man hides his methods of workshop practice he is merely trying to conceal his fear of competition. It is this behaviour that has helped to curtail horology as a profession.

Once the student has been shown a method of performing the many different kinds of work required for making a watch he can develop the confidence that comes from knowing there is nothing to be afraid of. For this reason I have given what some readers may at times think is a laboured description of the preparation or execution of some aspect of the work. But I have tried to do this only when it is a matter that I know from experience has puzzled a student. My plan has been to present the subject to the student as if he were looking over the shoulder of the watchmaker as the progress of the work in hand is explained. All the work described has been done in my workshops and the results are illustrated in colour.

The drawings have been prepared to show the process and sequence of the work in progress. In many instances the text merely assures the reader that there is no unillustrated intermediate stage. In this way it is intended that the student may read the chapter relating to the work in hand and then make future reference only to the drawings. In preparing and planning the illustrations I have been fortunate to have the services of Mr. David Penney whose combination of skilled draughtsmanship and horological interest has meticulously emphasized the written instruction. In order to be sure that the text fully explained the subject, the drawings were made from a combination of my sketch of the requirements and Mr. Penney's interpretation of the manuscript. In that way several misunderstandings could be mutually resolved to the ultimate benefit of the reader. An additional merit of the drawings is that a study of their skilled execution will greatly benefit the student's general standard of work.

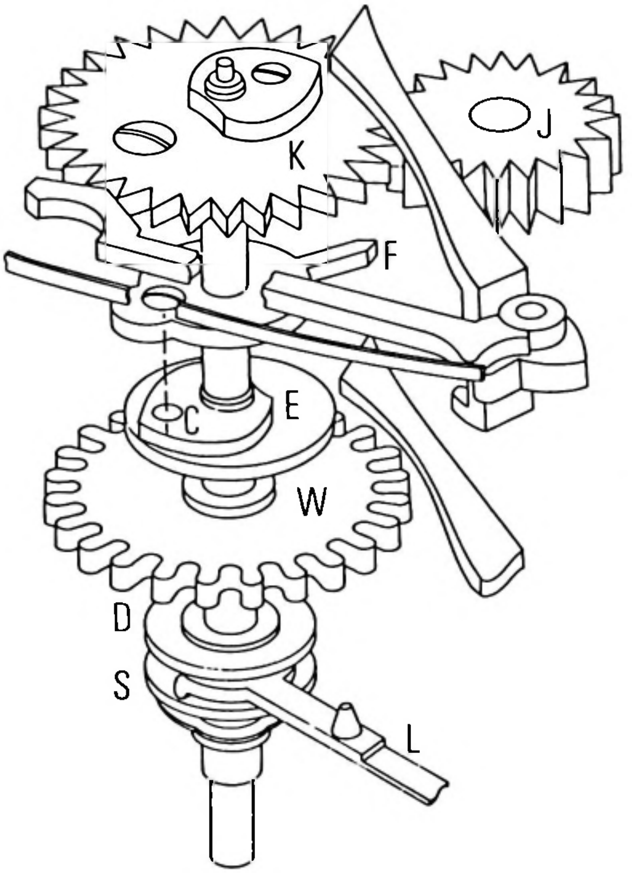
The surface texture and form of finish of components, much enlarged by photography, are shown in coloured illustrations. These include every type and shape of component of the complete watches that are also illustrated. It is my hope that they will help the student towards an understanding of finish, style and shape that reflect the art of the watchmaker rather than the engineer. The individual will of course ultimately develop his own style.

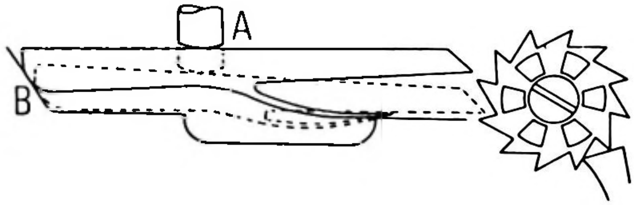
Throughout the book I have avoided the study of theory of physics and its mathematical application. It is true that in Swiss factories the technicians arrive at most decisions by mathematical analyses of their problems. It may be that they are right to do so but I have never found it necessary. This book concerns itself mainly with work done in my own workshops, but the chapter on escapements contains descriptions of very old escapements no longer used. I feel that without an understanding of the deficiencies of these old escapements it is not easy to understand the relative merit of the later, detached escapements. And again, without an understanding of obsolete, detached escapements it is not possible to devise new detached escapements that will sustain the watch for years to come.

It should be the ambition of every professional to make a contribution to his field of study. This can only be achieved by constant striving for improvement. In watchmaking that contribution may be scientific, intellectual or aesthetic, for watches combine these three aspects to a degree depending upon their maker's interest. Continuous study and practice are the ingredients for binding them into a successful whole. Much work will be necessary before this success is realized, but if this book can encourage a fresh start by a new generation to take up once again the practical development and manufacture of the self-contained portable timekeeper, it will have fulfilled its purpose.

George Daniels
London, 1981

Plate 0





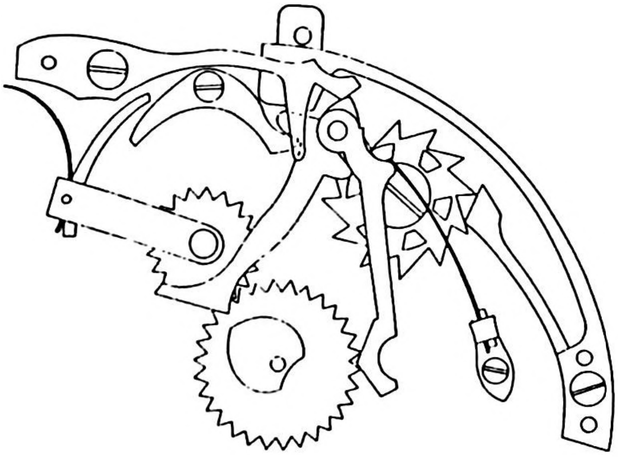
Action of Chronograph

The wheel *W* is free-running on the hollow arbour *E* and rotates continuously in engagement with the toothed edge of the *tourbillon* carriage.
The cam *C* and finger *F* are fixed to *E*. The wheel *K*, with its cam, is fixed to the minute-recording arbour passing through *E*.
When clutch lever L is raised, spring *S* will press *W* into contact with faces *D* and the underside of *E* to start the seconds hand. At each turn of *E* the finger *F* will engage the intermediate wheel *J* to advance *K* one tooth for each elapsed minute. When *W* is disengaged to stop the seconds hand, both cams can be reset by the zeroing levers.

Action of Pillar Wheel

Pressure at *A* from the chronograph button in the case will cause the pillar wheel pawl to slide to the right, down the ramp at *B* to engage a ratchet tooth. Further pressure will advance the pillar wheel one tooth. When released the pawl spring will raise the point of the pawl so that it will be pushed back to the left by the slope of the ratchet tooth.

The diagrams below show the action engaged to the left and disengaged to the right with cams zeroed.



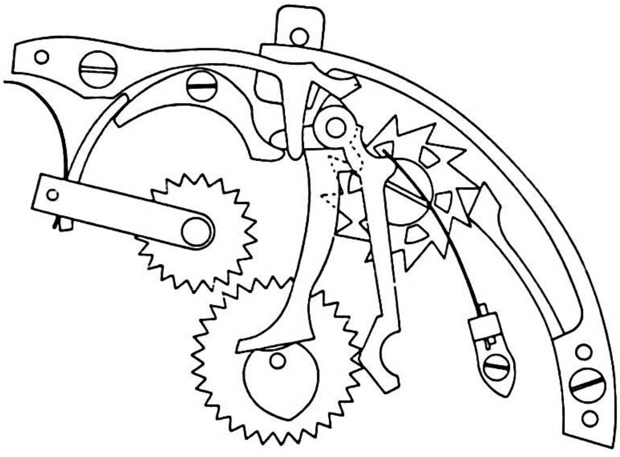
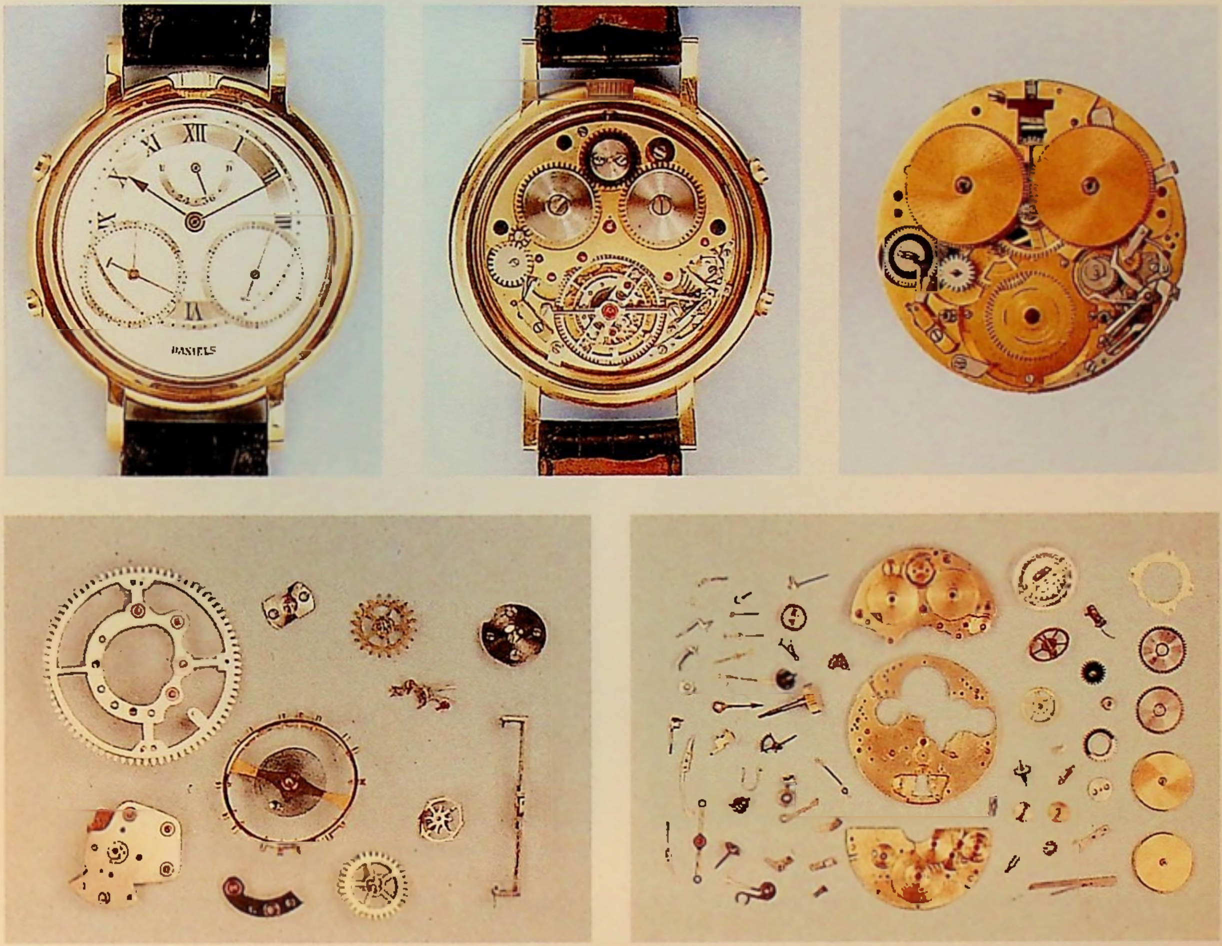


Plate I



Chronograph wrist-watch, four-minute *tourbillon* with Daniels co-axial escapement, Invar balance spring with terminal curve free sprung, chronograph set into the plate to avoid increased height to the movement. Silver dial with subsidiary dials, for continuous seconds to the right, chronograph seconds with minute indicator to the left, reserve of winding sector above, gold hands.

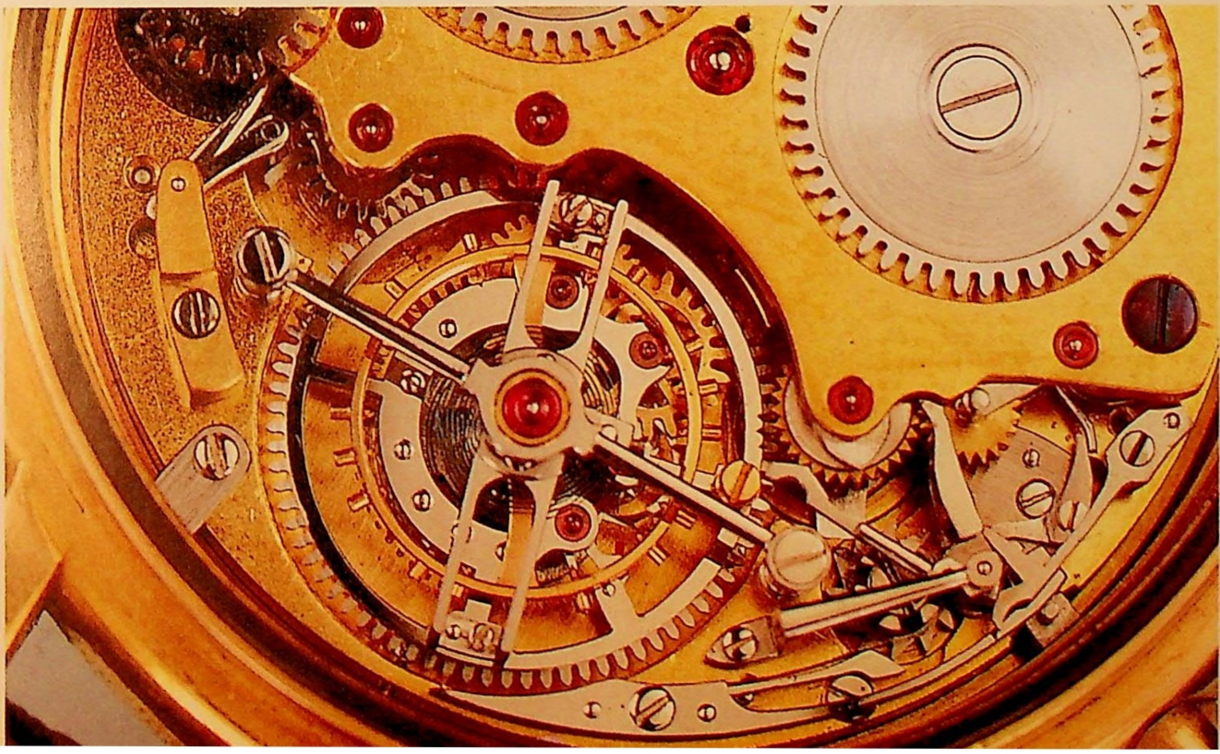
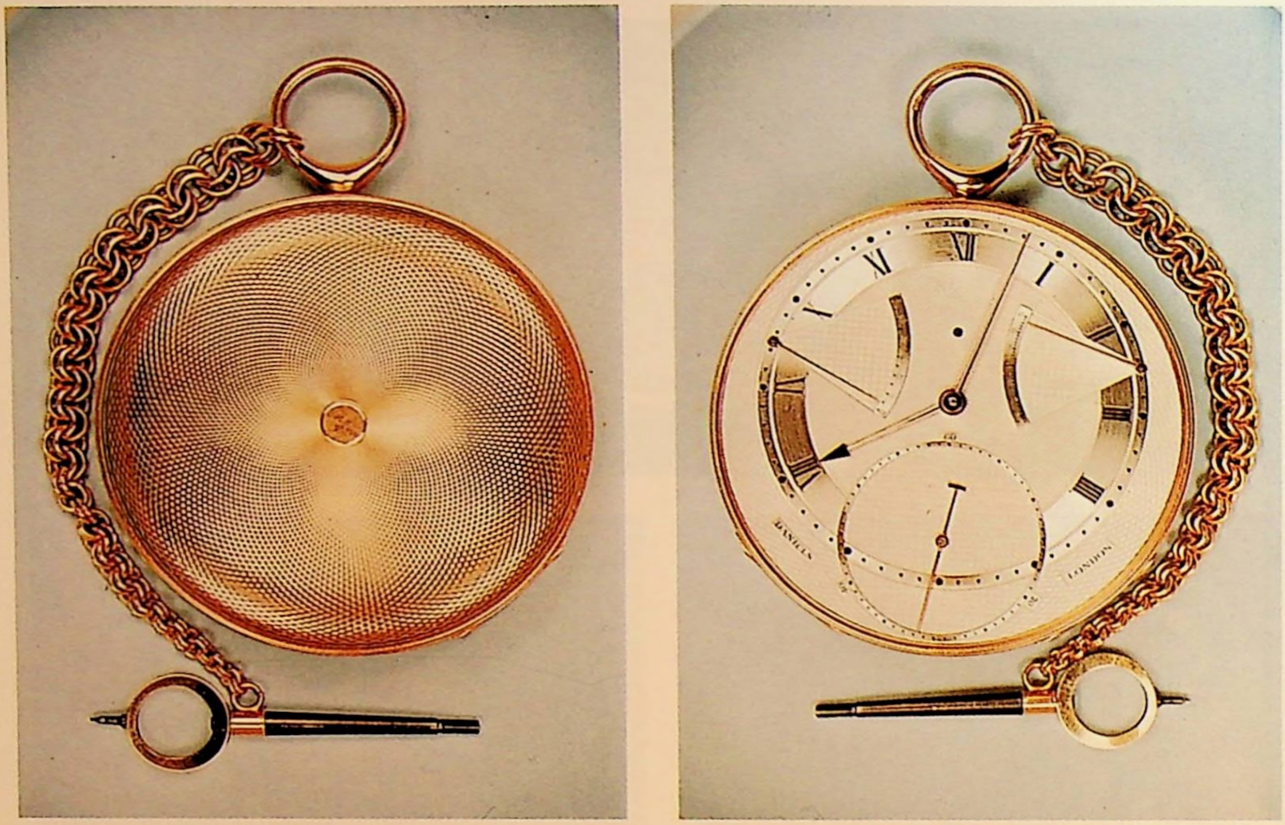
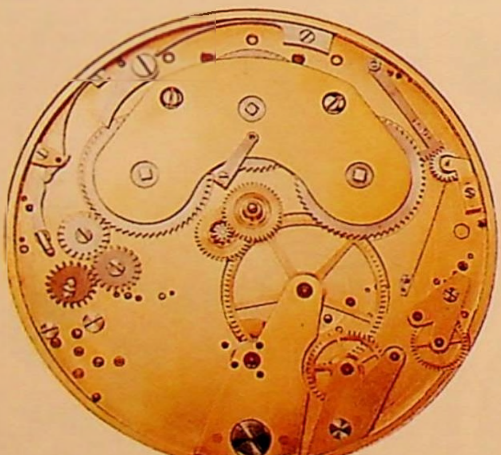
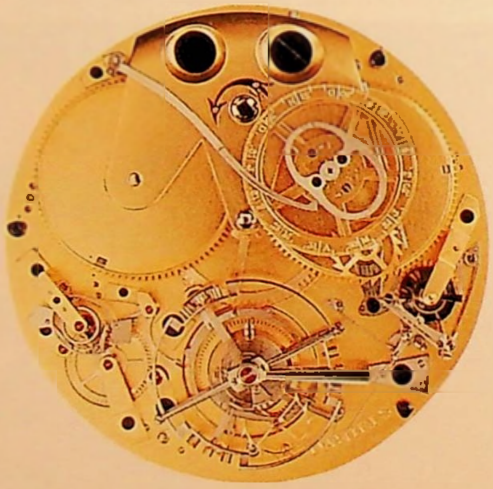


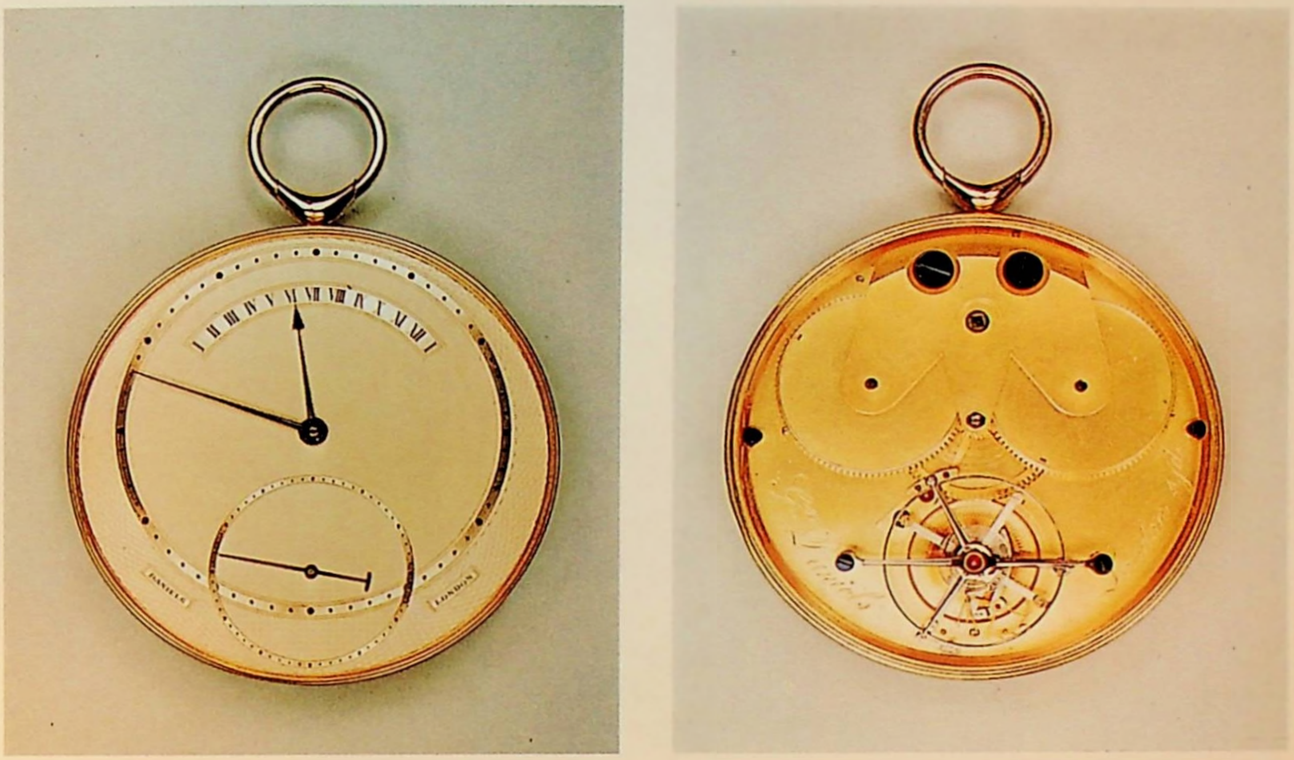
Plate II



Watch with one-minute *tourbillon* with fifteen-second remontoir, two-armed carriage, reversed spring-detent escapement, stainless steel balance with recessed screws, Elinvar balance spring with terminal curve, silver engine-turned dial with sectors for Equation of Time and state of winding, gold hands, engine-turned gold case. 60 mm diameter.







One-minute *tourbillon* with Earnshaw spring-detent escapement, three-armed carriage, stainless steel balance with eccentric weights for regulation, Elinvar balance spring with terminal curve, silver engine-turned dial with retrograde hour hand, blued steel hands, gold engine-turned case. 60 mm diameter.

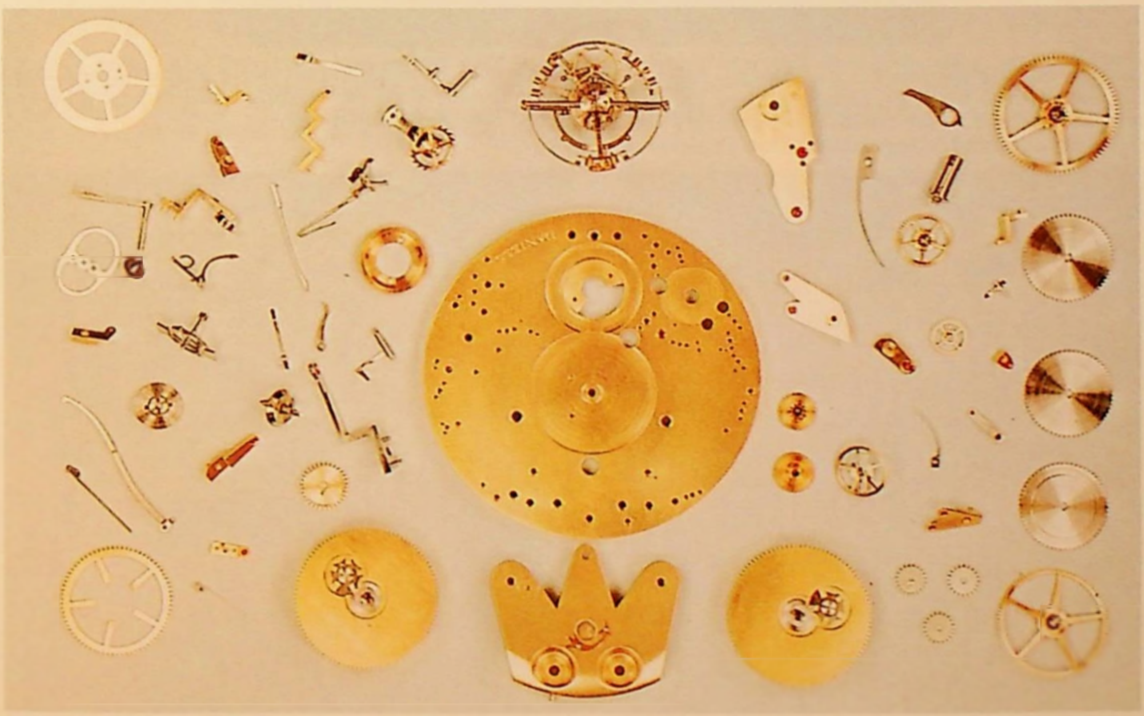
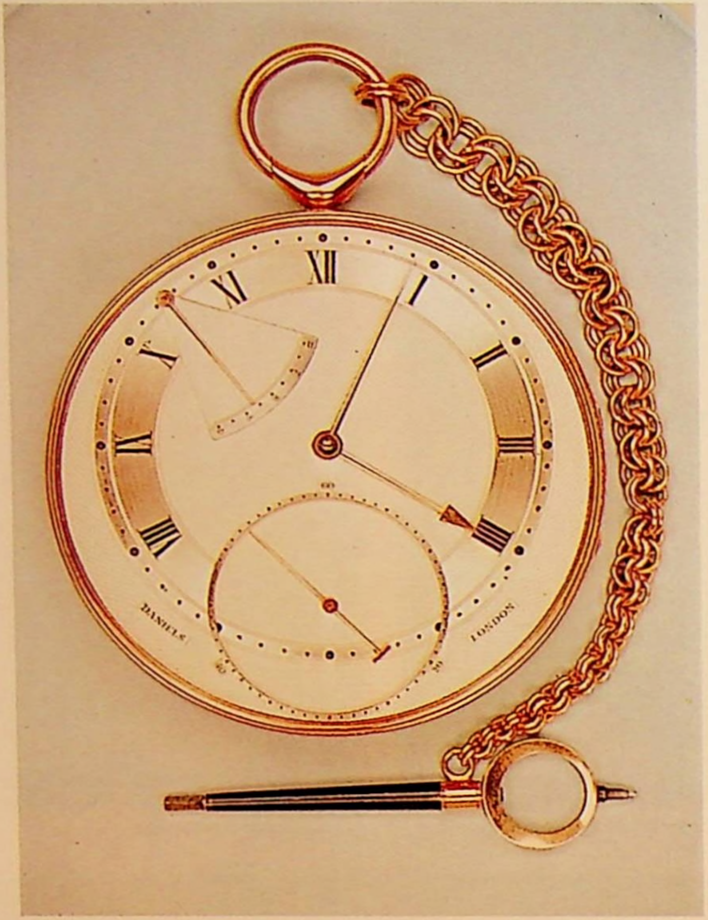


Plate IV



Watch with one-minute *tourbillon* with Daniels co-axial escapement, two-armed carriage, stainless steel balance with bi-metallic attachments for residual temperature correction, eccentric weights for regulation, Elinvar balance spring with terminal curve, silver-engine-turned dial with sector for the state of winding, gold hands, gold engine-turned case. 60mm diameter.

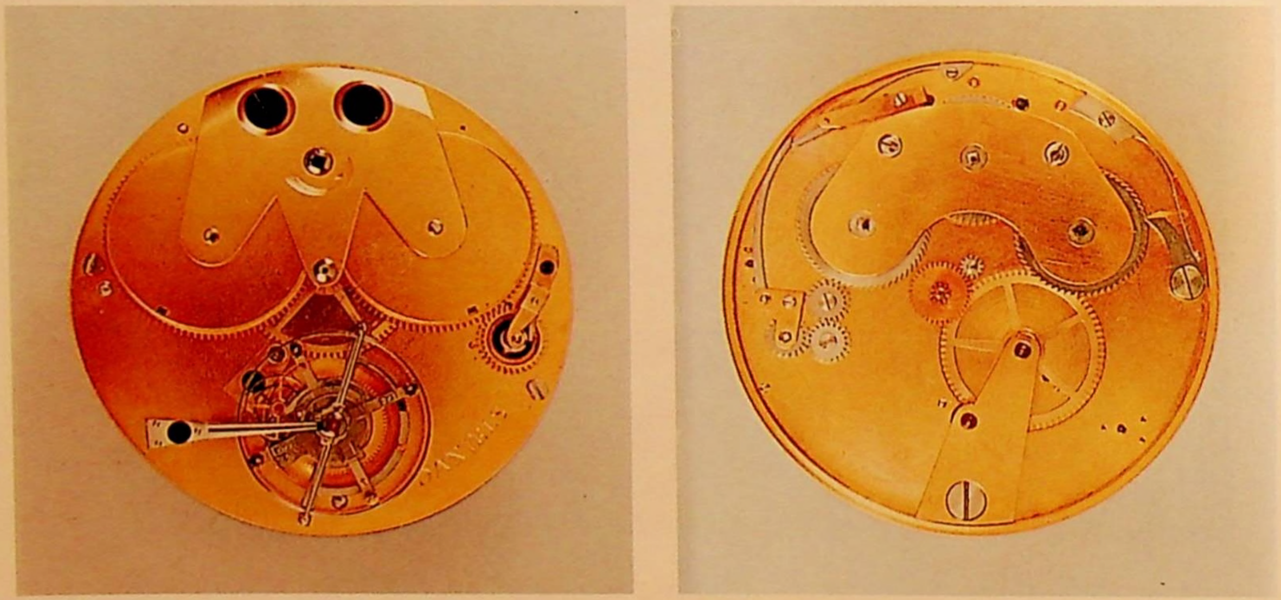
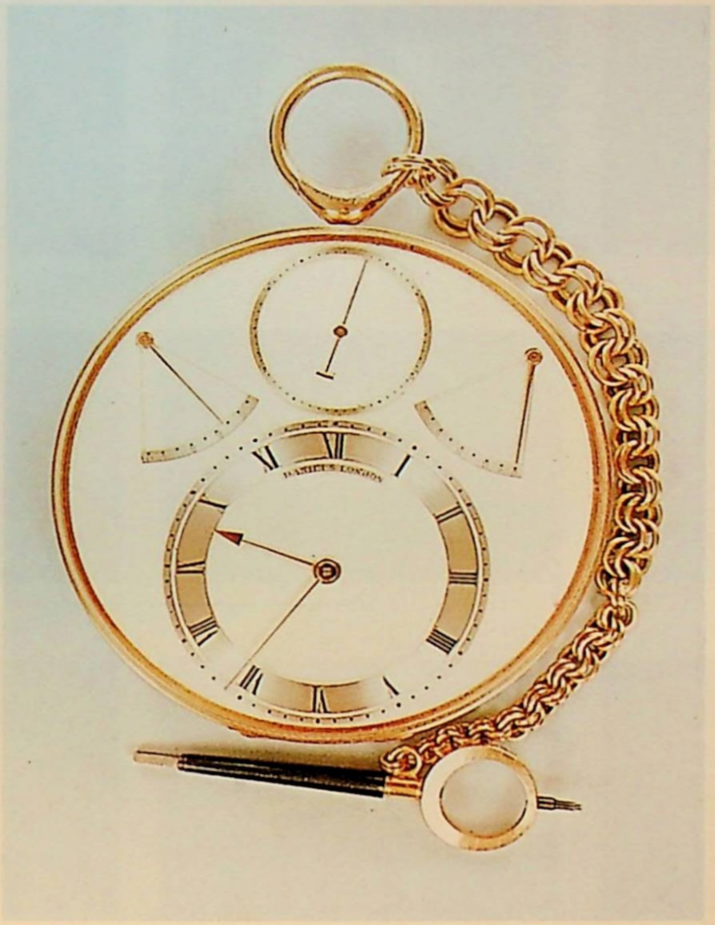


Plate V



Watch with two trains and Daniels independent double-wheel escapement, stainless steel balance wheel with eccentric weights for regulation, Elinvar balance spring with terminal curve, silver engine-turned dial with sectors for thermometer and state of winding, seconds above with provision for setting to zero, gold hands, gold engine-turned case. 59 mm diameter.

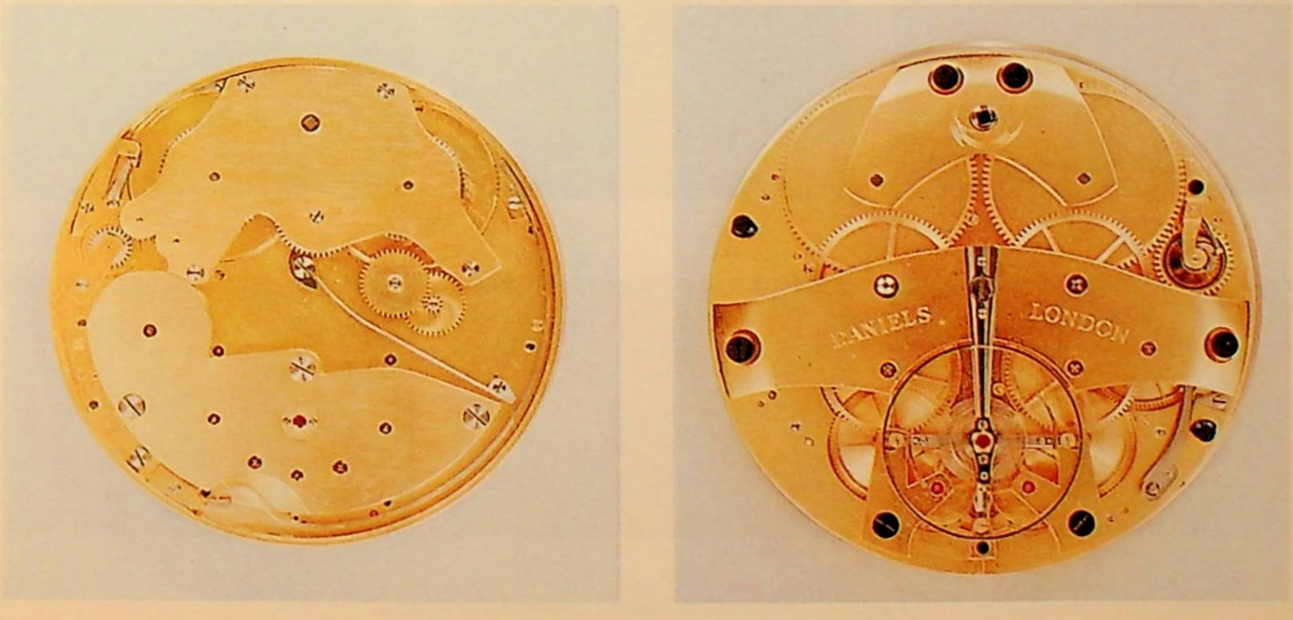
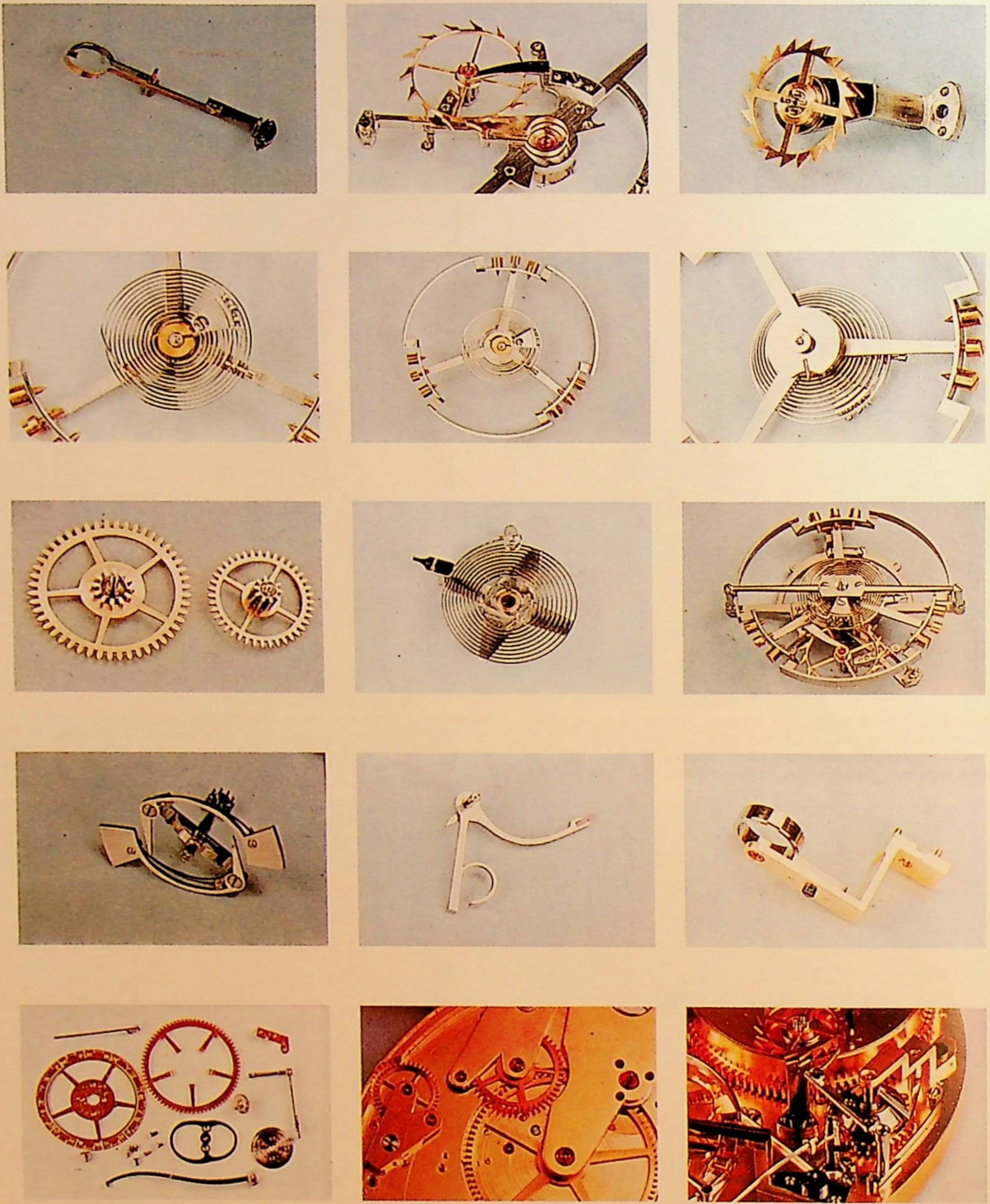
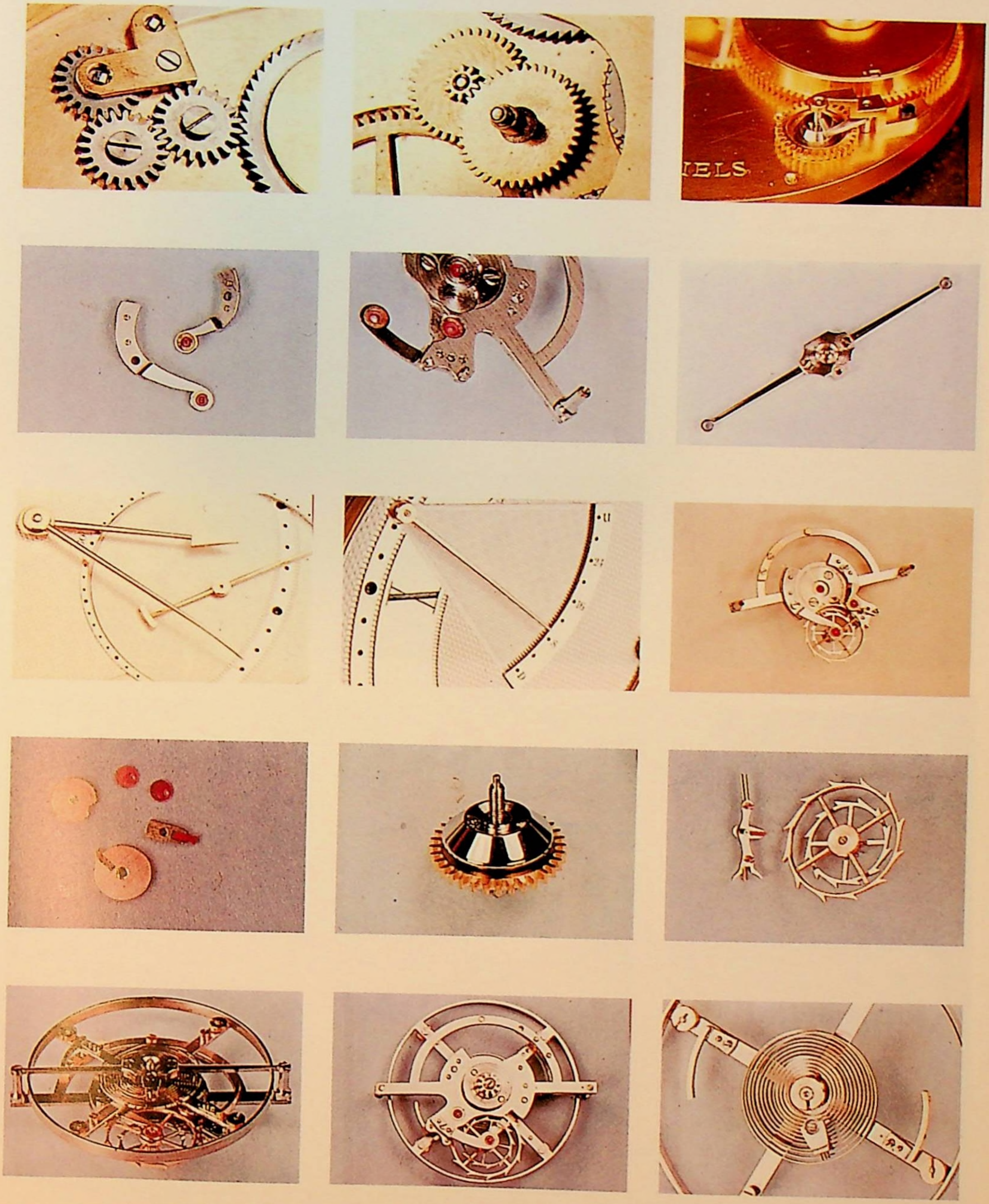


Plate VI



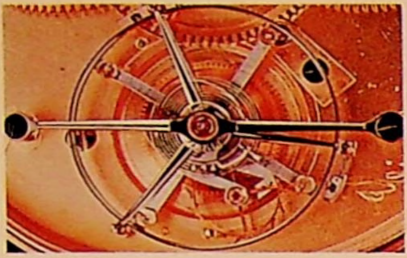
Component details of the watch illustrated in Plate II

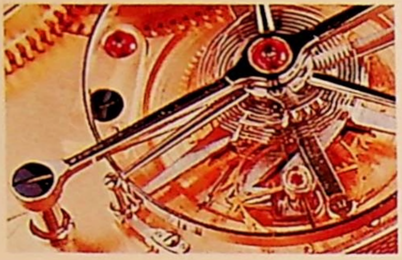
Plate VII

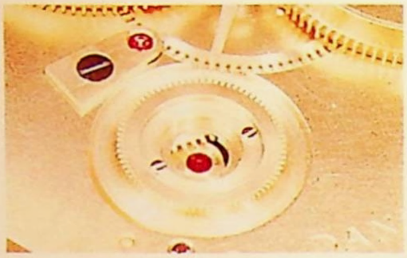


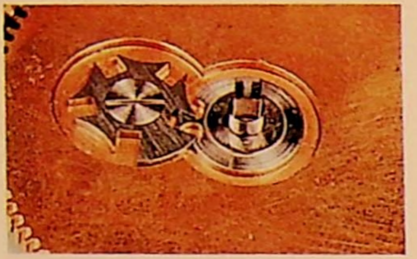
Component details of the watch illustrated in Plate IV

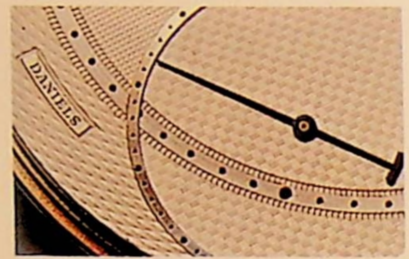
Plate VIII

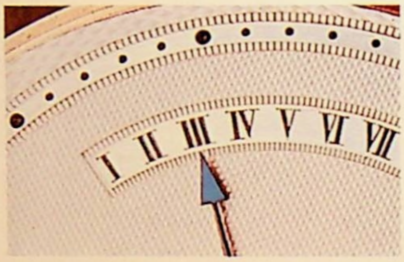


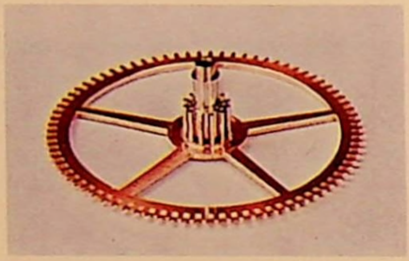


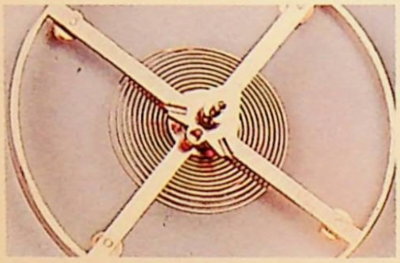


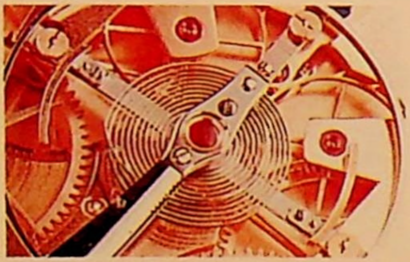


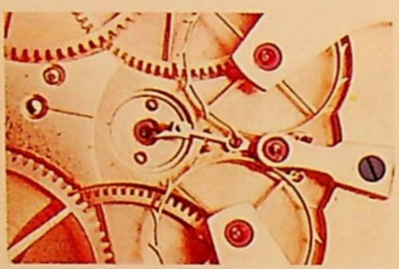


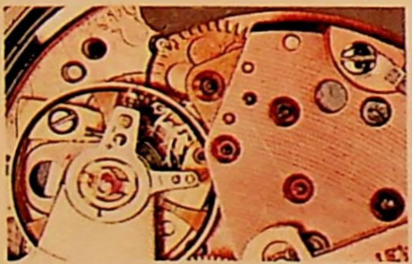

I II III IV V VI VII

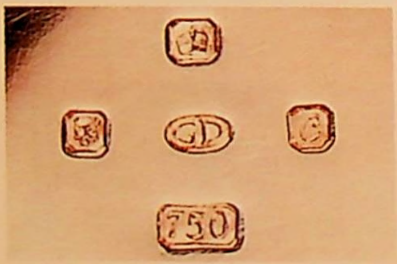


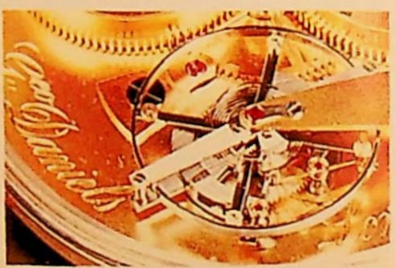






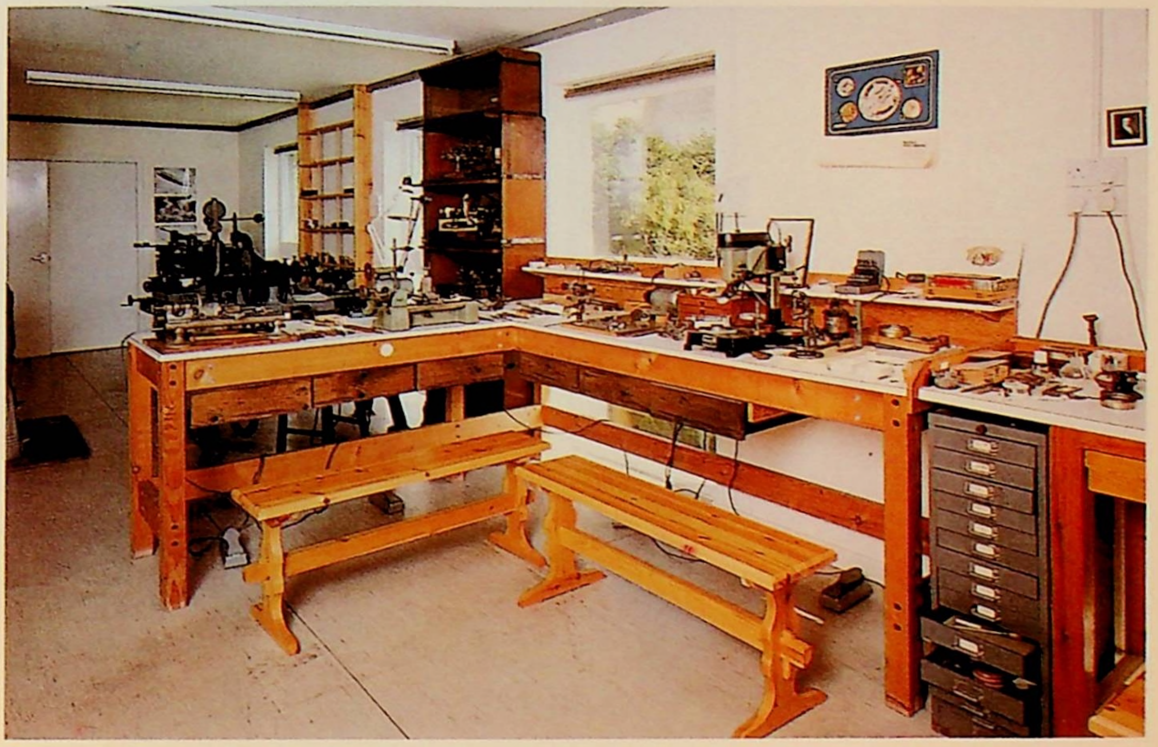




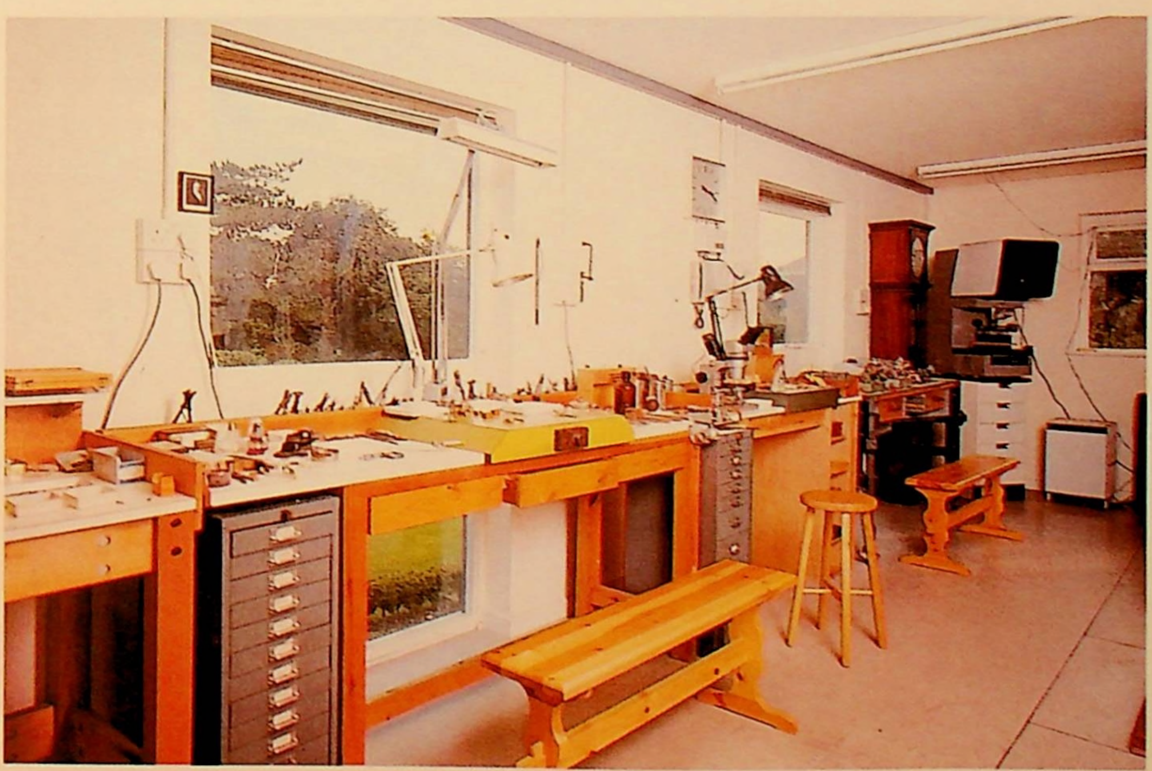

Geo Daniels

1–7 Component details of the watch illustrated in Plate III.
8–12 Component details of the watch illustrated in Plate V.
13 Co-axial escapement fitted to wrist-watch movement.

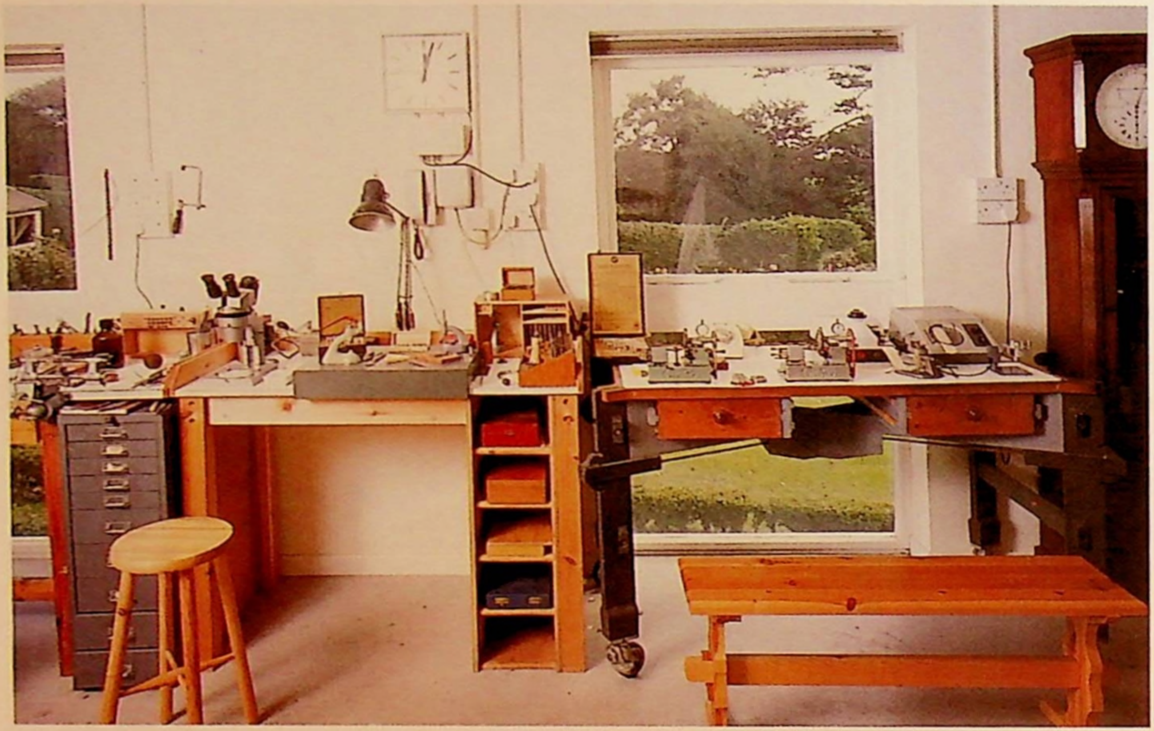
14 Hallmarks of the Worshipful Company of Goldsmiths, London, and case maker's punch mark.
15 Pivoted detent *tourbillon* carriage.



1 East wall looking north, showing small work benches with 8 mm lathes, jewelling lathe, large and small drilling machines.

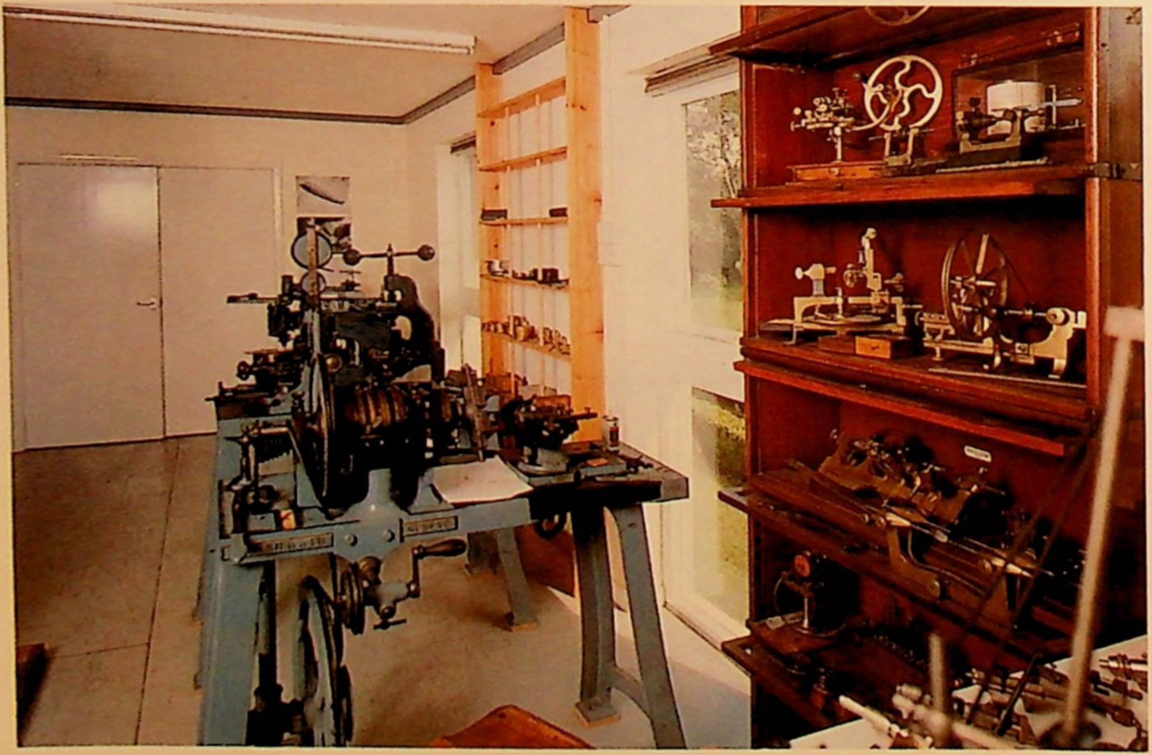


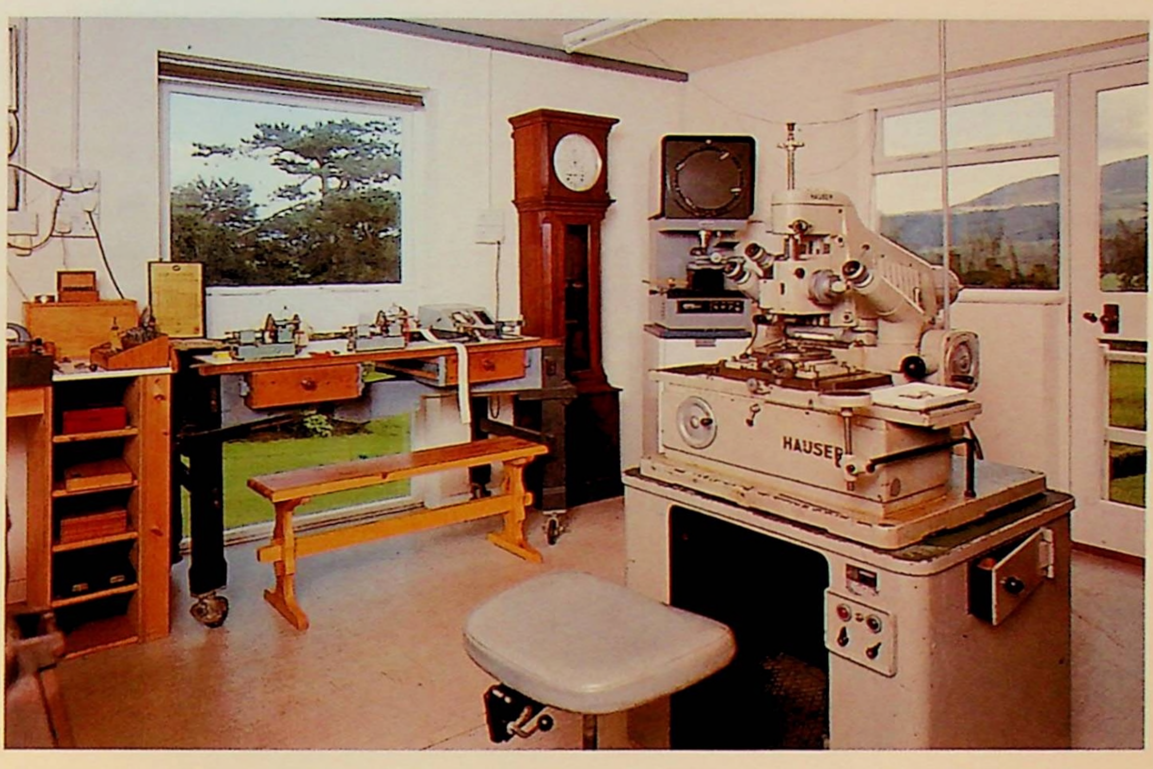
2 East wall looking south, showing finishing bench with raised centre, jewelling bench, timing bench, Haswell regulator, optical comparator.



1 Detail of jewelling and timing benches, showing hand turns, jewelling tools, staking tools, pivot polishing machines, timing machines for long and short run observations. The clock above is radio monitored to show exact GMT.

2 Detail of north-east corner showing engine-turning machine, pantograph milling machine, case-making press, rolls and anvil. The antique brass tools and engines can occasionally be very useful and were at one time the everyday tools of the watchmaker.





1 Detail of south-east corner showing optical comparator and jig borer for small, high-precision work.

2 Detail of raised finishing areas showing the watch illustrated in Plate XIII at an advanced stage of making. The parts are ready for assembly and examination prior to final finishing and gilding.

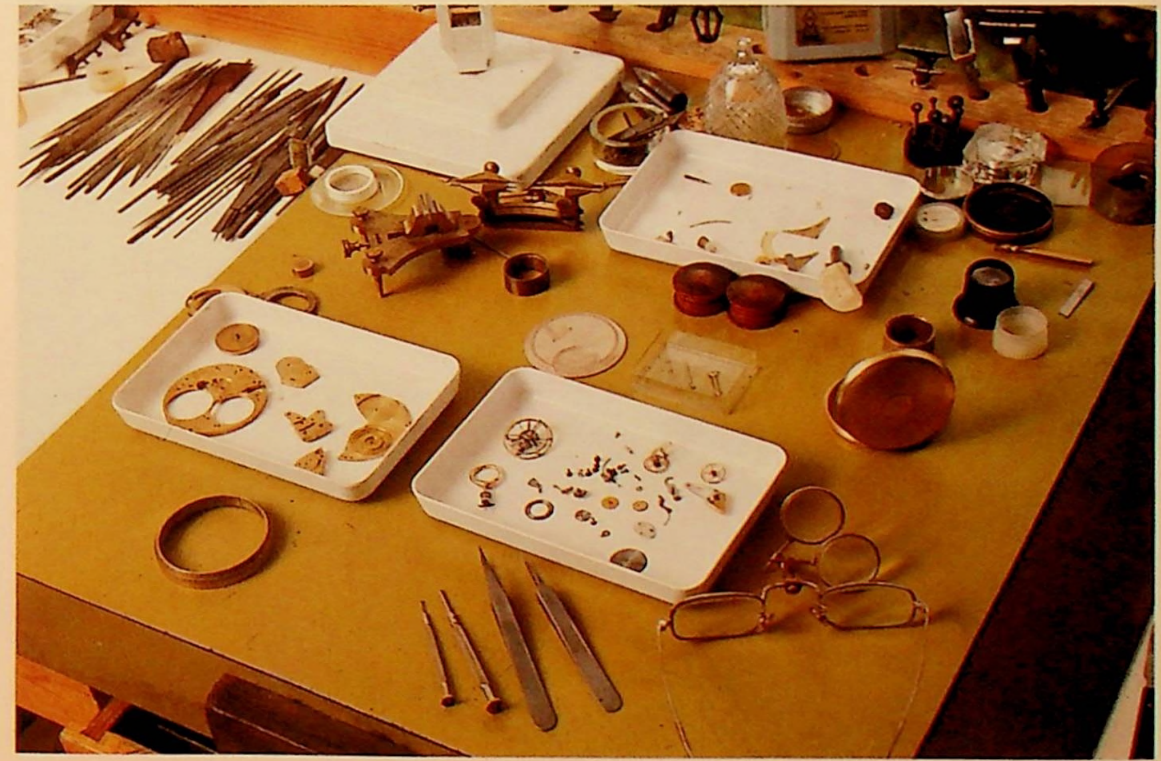
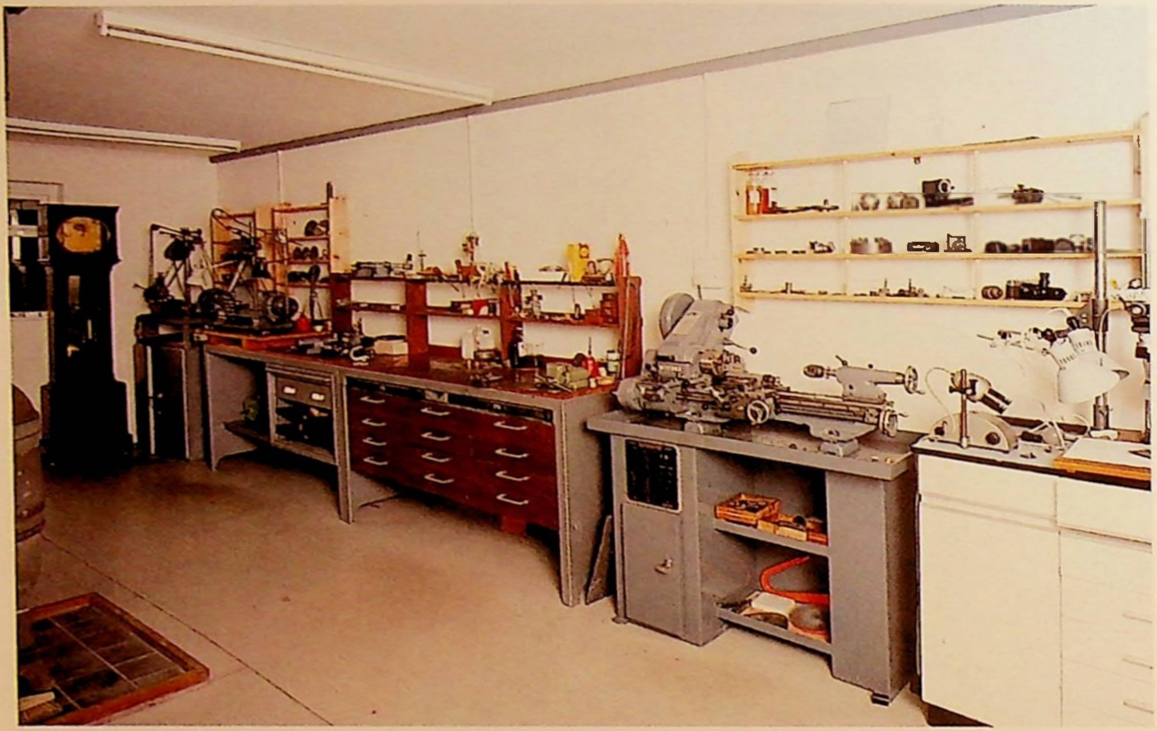
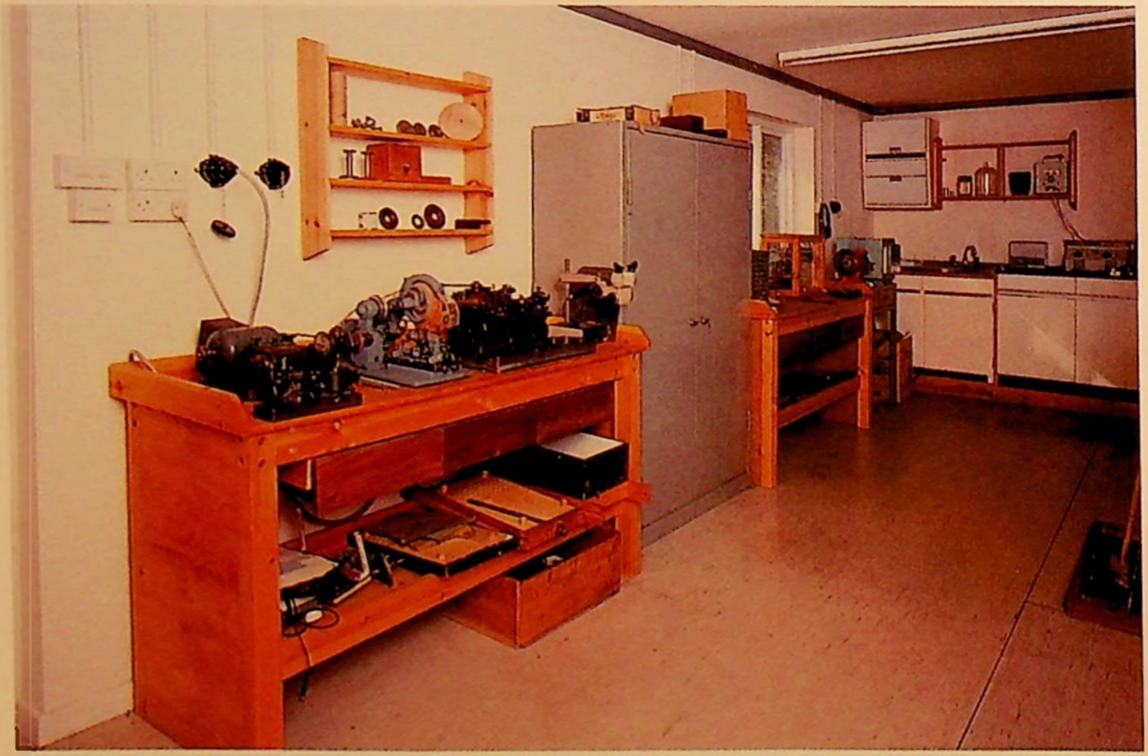


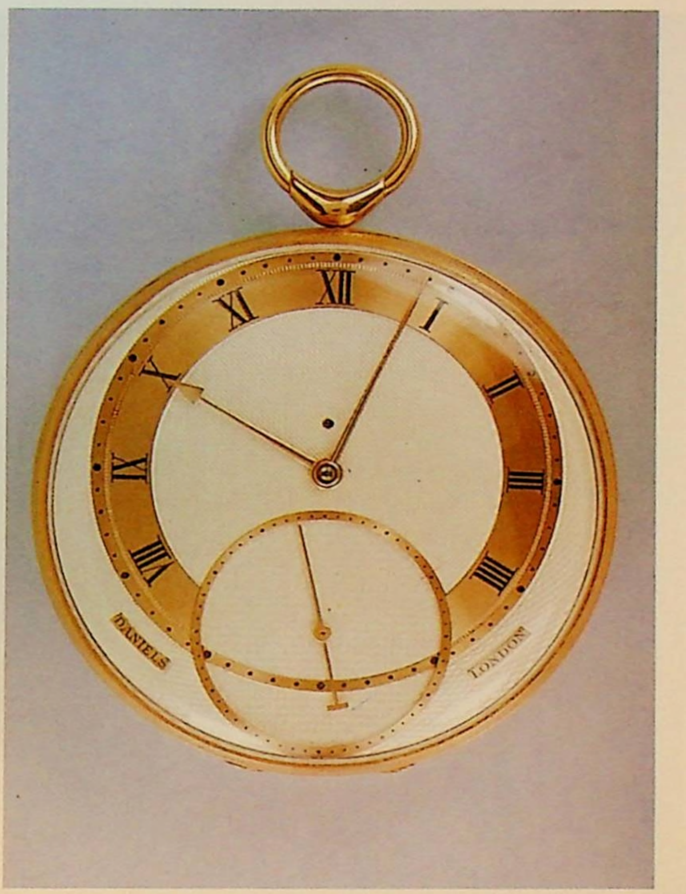
Plate XII



1 West wall looking south, showing photographic bench, screw-cutting lathe, general work benches, precision lathes for turning, wheel-cutting, etc.

2 West wall looking north, showing pinion cutting and polishing bench, furnace, wet benches with ultrasonic bath and electro-plating apparatus.





Watch with one-minute *tourbillon* with Daniels co-axial escapement and keyless winding. Six-armed carriage with three-armed upper bridge and outer ring of driven teeth. Three-armed stainless steel balance with eccentric gold weights for regulation. Silver engine-turned dial with inset gold chapter rings and signature plaques. Gold engine-turned case. Three-position pendant. First position as illustrated. Second and third positions for winding and hand setting.

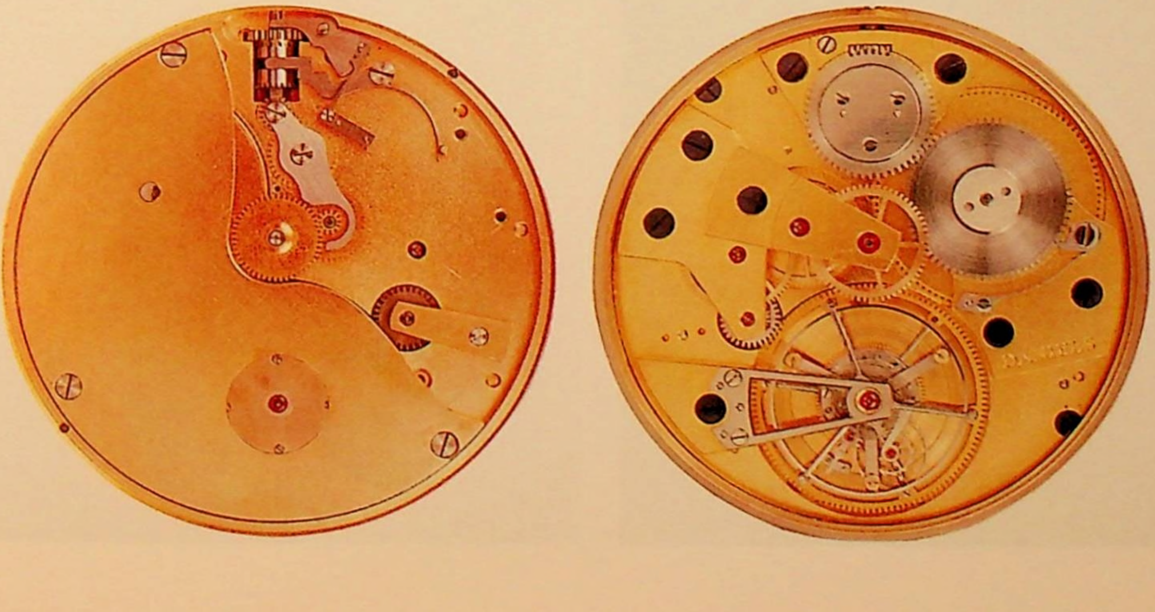
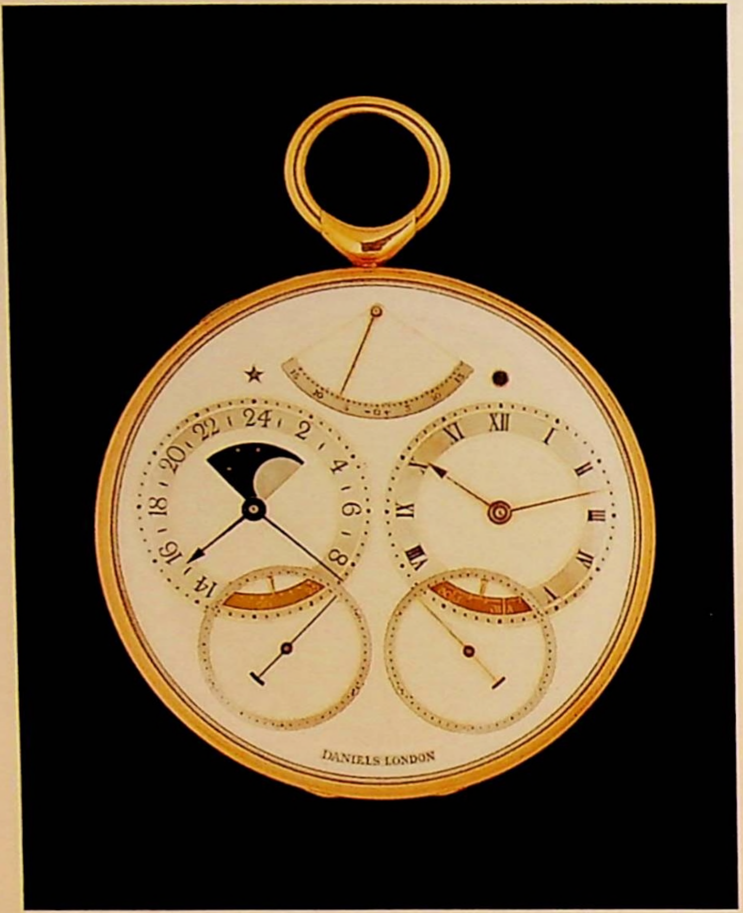
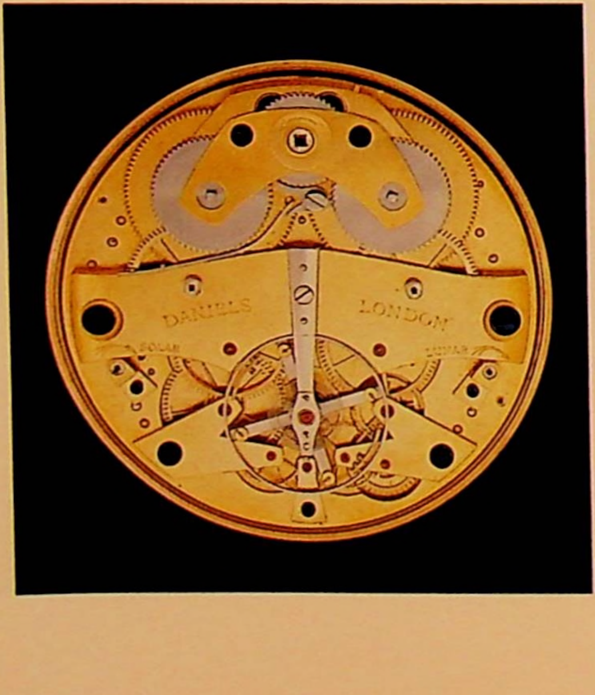


Plate XIV



Watch showing solar and sidereal time. Independent trains with Daniels double escapement with wheels of unequal numbers of teeth. Silver engine-turned dial with 24-hour chapter ring for sidereal time on the left, and containing moon-phase disc and gilt sector showing age of the moon. Mean solar chapter ring to the right and containing aperture for the calendar. Seconds below for sidereal and mean solar. Sector for equation of time above. Gold engine-turned case.



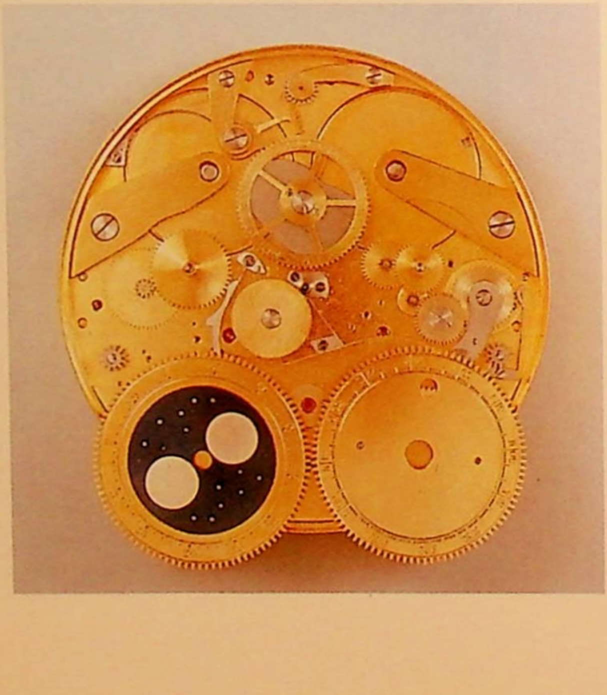
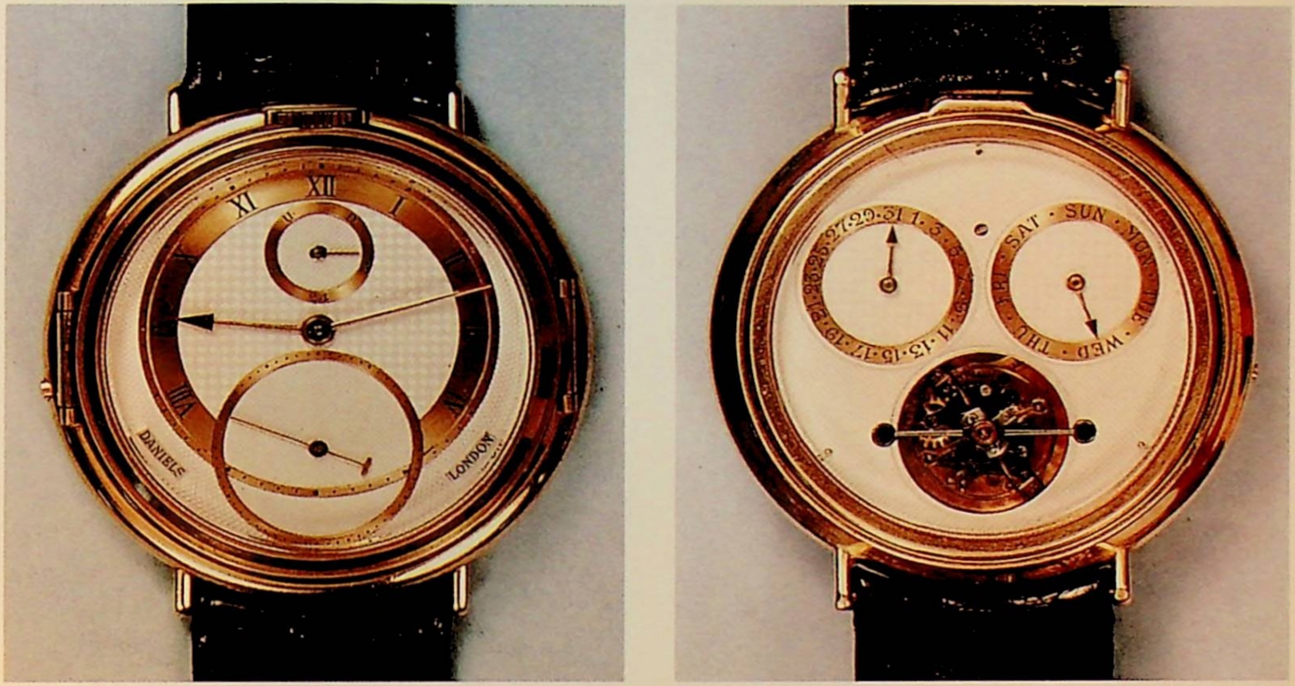
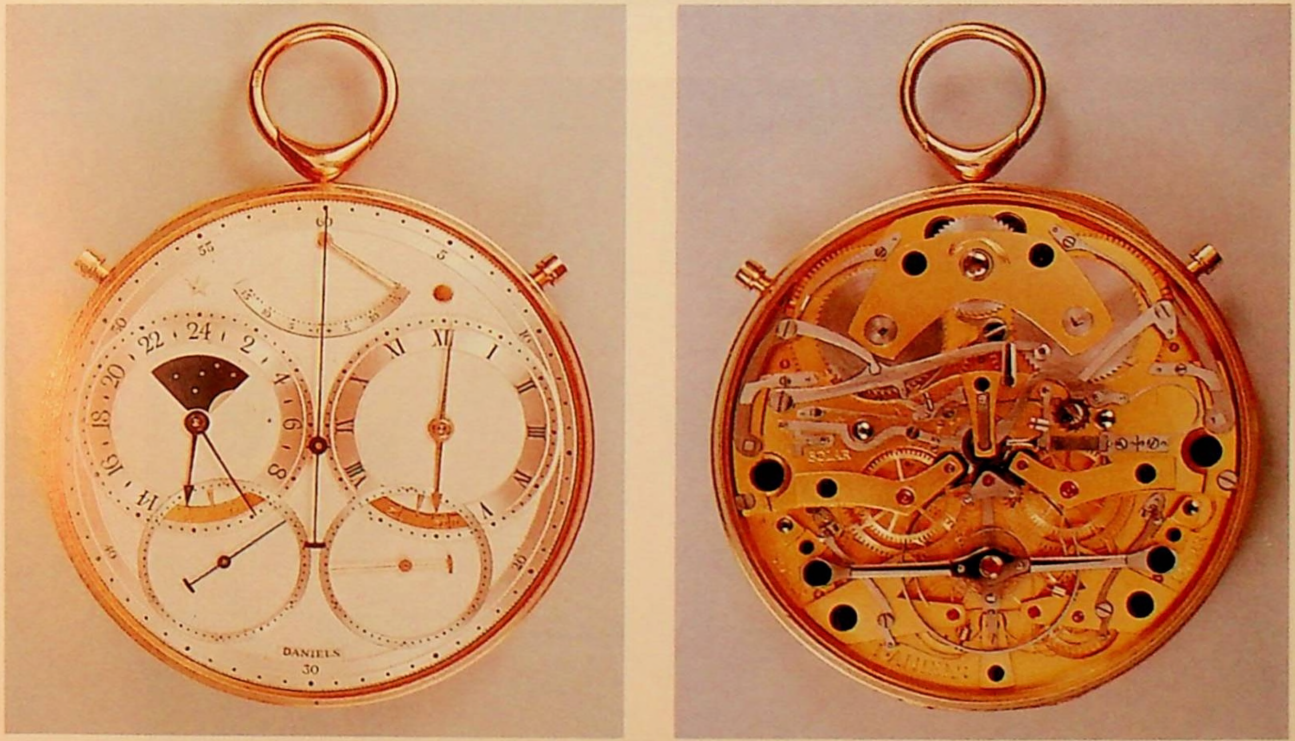


Plate XV

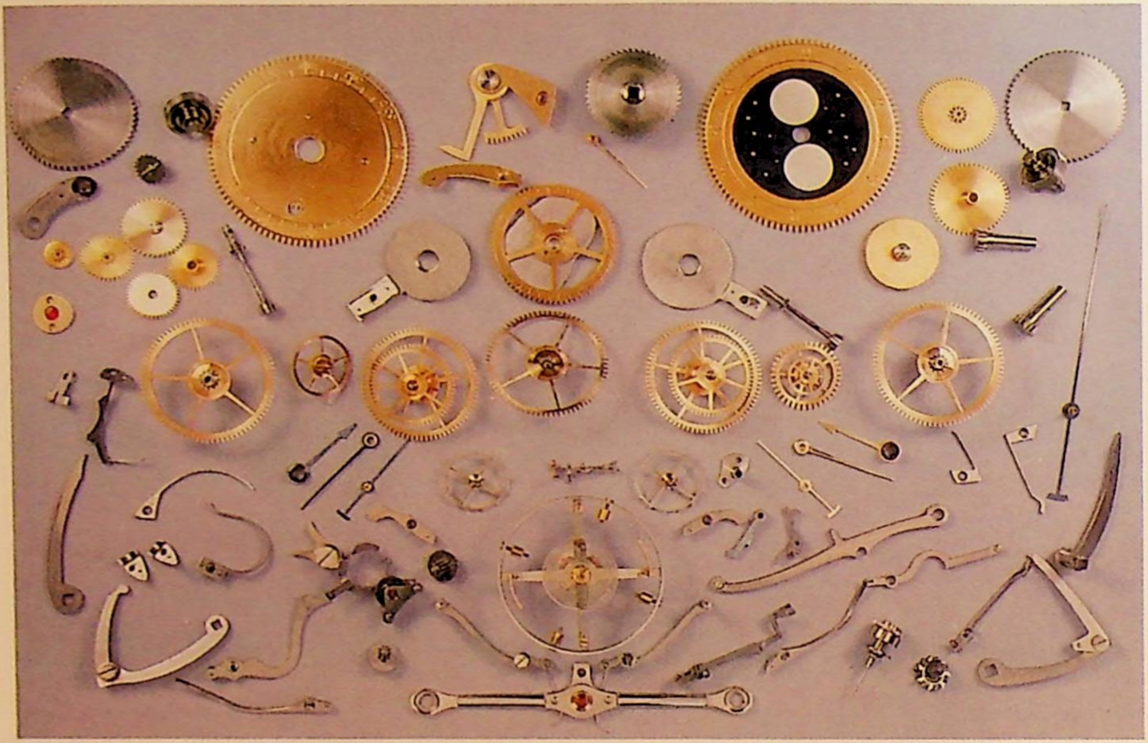


Wrist-watch with one-minute *tourbillon* with Daniels co-axial escapement, balance with eccentric gold adjusting weights. Invar balance spring with terminal curve free sprung. Silver dial with gold chapter rings, subsidiary dial for seconds and reserve of winding. Gold hands. Reverse dial with day and date revealed by pressing the button at 8 o'clock position while the watch is carried on the wrist. Signed 'Daniels London'.



Solar and sidereal watch with chronograph to show solar or sidereal seconds as required. The dial as for Plate XIV but with the addition of centre seconds. Double-wheel escapement with wheels of 13 for sidereal time and 14 for solar time. Gold engine-turned case. For a description of the mechanism see Plate XVIII.5

Plate XVI



Details of solar/sideral watch illustrated in Plate XV.

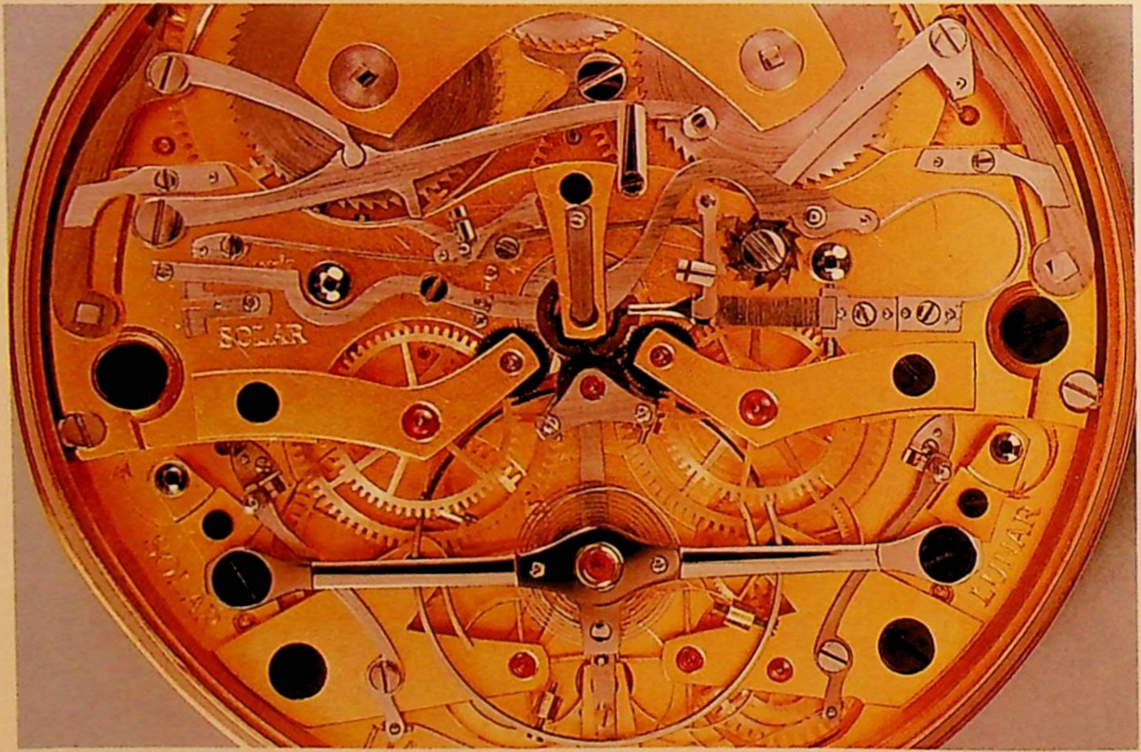

SOLAR
SOLAR
LUNAR

Plate XVII

Wheel arrangement for solar/sideral watches

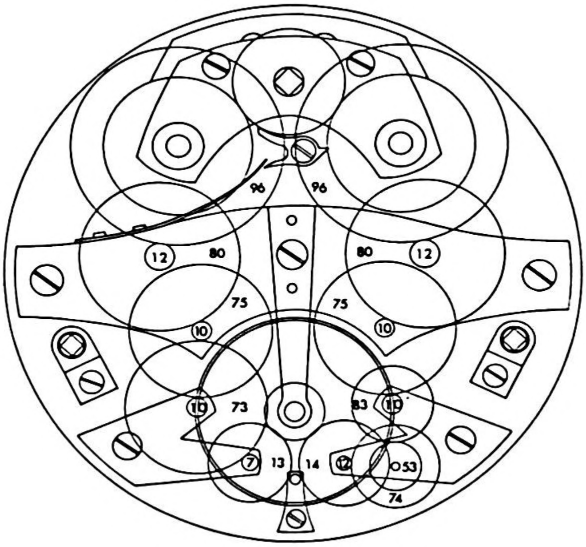


Fig. A

Fig. A Wheel train calculations for the solar/sidereal watches

Sidereal train

$$80 \times \frac{75}{10} \times \frac{83}{10} \times \frac{37}{53} \times \frac{28}{6} = 16{,}268.571 \text{ vibrations per solar hour}$$

Solar train

$$80 \times \frac{75}{10} \times \frac{73}{10} \times \frac{26}{7} = 16{,}224.15 \text{ vibrations per solar hour}$$

$$\frac{16{,}268.571}{16{,}224.15} = 1 : 1.002737924$$

A better figure would be 1.002737909 and the difference is 0.000000015. 0.15^{-8} x 31,557,600 solar seconds per year = 0.4 seconds fast per year.

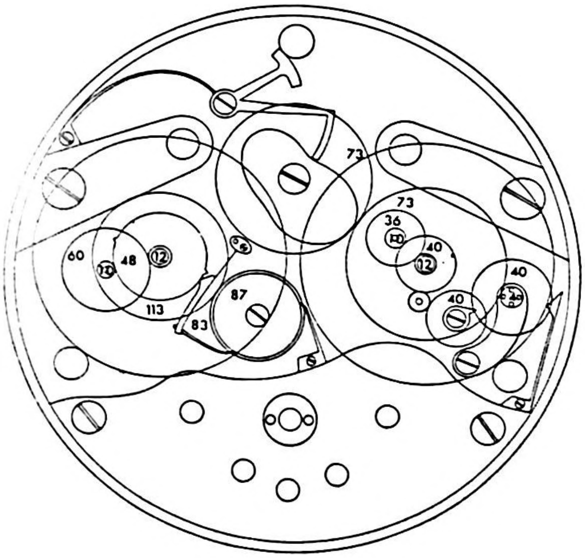


Fig. B

Fig. B Calculations for moon phases and equation of time

The moon train derives from the sidereal motion work:

$$\frac{87}{2} \times \frac{113}{83} = \frac{59.222891}{2} = 29.611445 \text{ sidereal days per lunar cycle}$$

$$\frac{29.611445}{1.002737909} = 29.530593 \text{ solar days per lunar cycle} = 0.422 \text{ second slow}$$

The equation is derived from the solar motion work:

$$\frac{73}{4} \times \frac{40}{2} = 365 \text{ days per revolution of the equation cam.}$$

Plate XVIII

Action of the chronograph mechanism

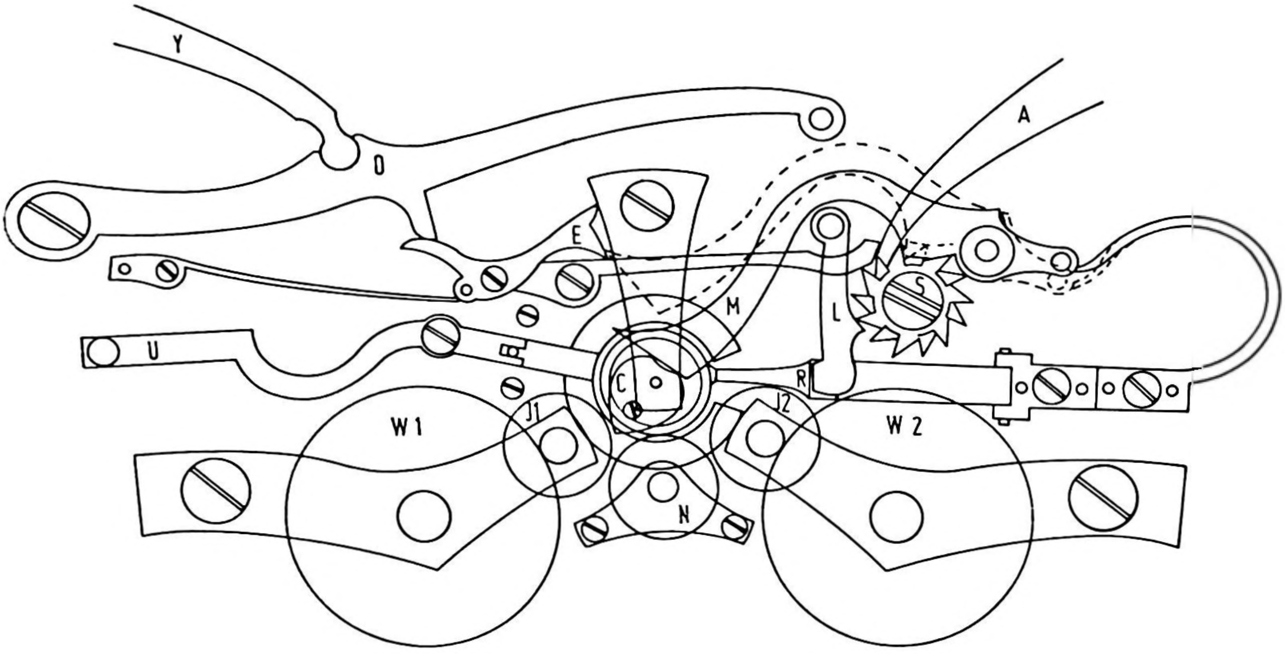


Fig. C

Fig. *C* The wheels *W1* of the solar train and *W2* of the sidereal train drive wheels *J1* and *J2* continuously while the watch is running. The intermediate wheeel *N* can be engaged by lever *U* with either *J1* or *J2* to drive the seconds hand, carried on the arbor of the wheel C, to show either sidereal or solar seconds. As illustrated, lever *L* is resting on the ramp of clutch lever *R* to disengage the clutch and stop the seconds hand. When *A* is pushed by the button in the band of the case, *S* is turned one tooth to release lever *L* and allow *R* to rise and engage the clutch carried on the arbor of the seconds hand. At the same moment zeroing lever *M* is raised to rest on catch *E*. When *A* is again pushed *L* is lifted on to the ramp of *R* to disengage the clutch and stop the seconds hand but *M* remains locked on *E*. To zero the seconds hand *Y* is pressed by the second button in the band of the case to lift *E* and release *M* to fall onto the zeroing cam on wheel *C*.

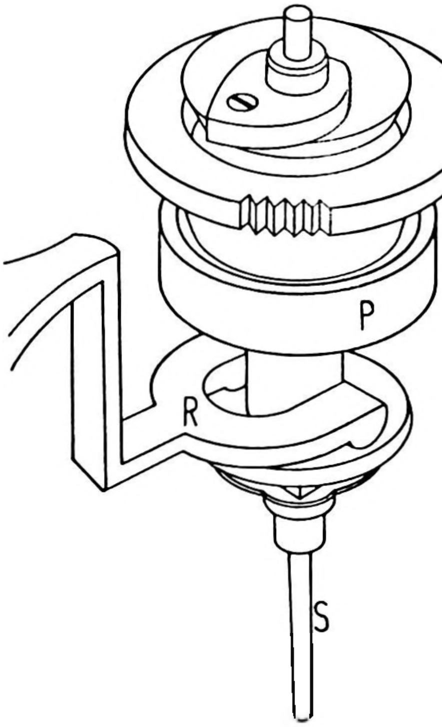
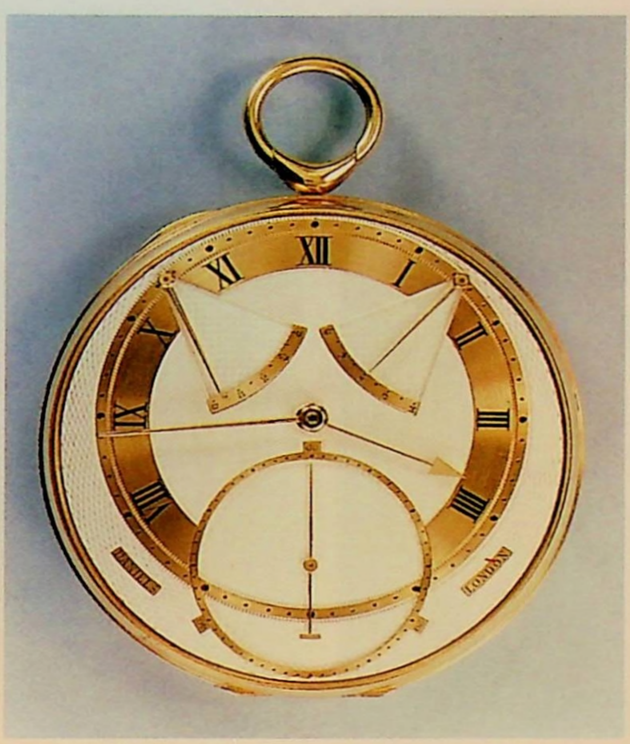


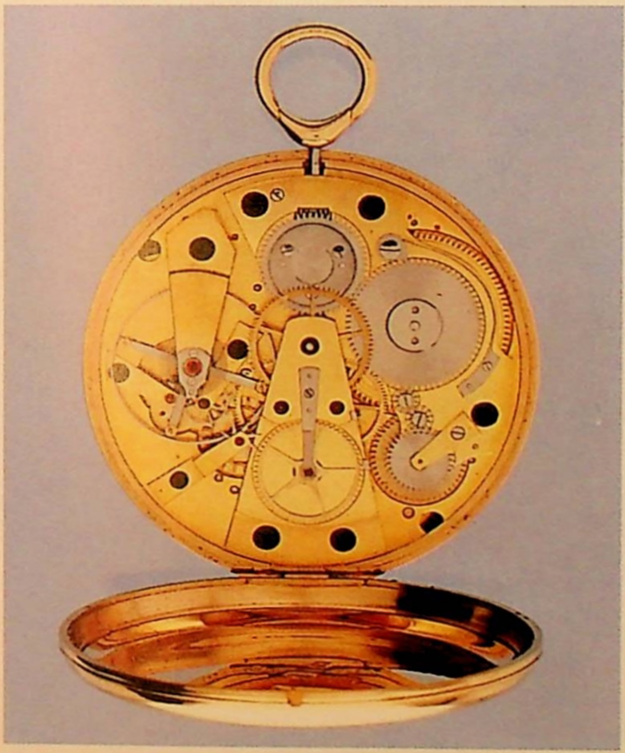
Fig. *D* The clutch is engaged by the bow spring beneath and released by the fork of *R* drawing down the clutch cone *P* to allow wheel C to rotate idly on the seconds arbor *S*.

Fig. D

Plate XIX


XII
I
II
III
IIII
X
IX
XI
DANIELS
LONDON

Pocket chronometer with Daniels co-axial escapement, steel balance with Invar spring with terminal curve, free sprung mechanism for indicating jump seconds, three-position pendant for winding and hand-setting, silver dial with gold chapters, subsidiary sectors for reserve of winding and thermometer. Signed 'Daniels London'.



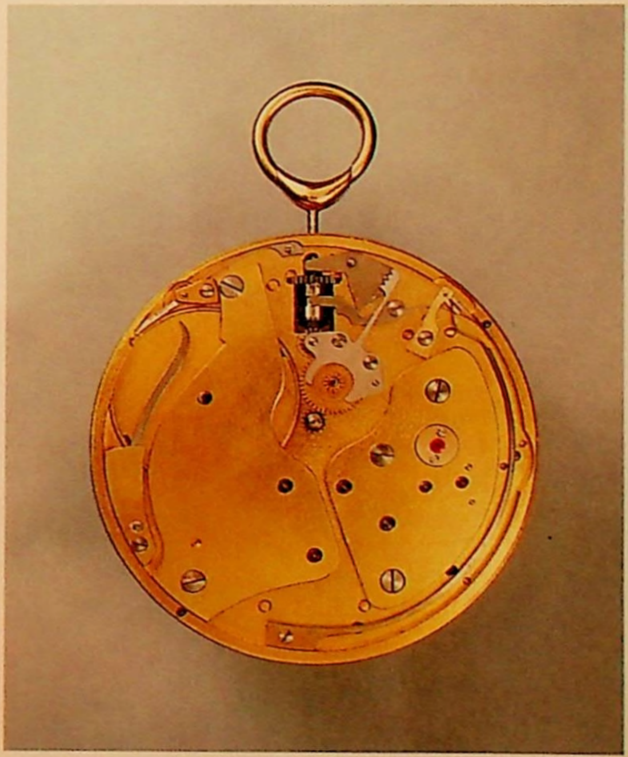
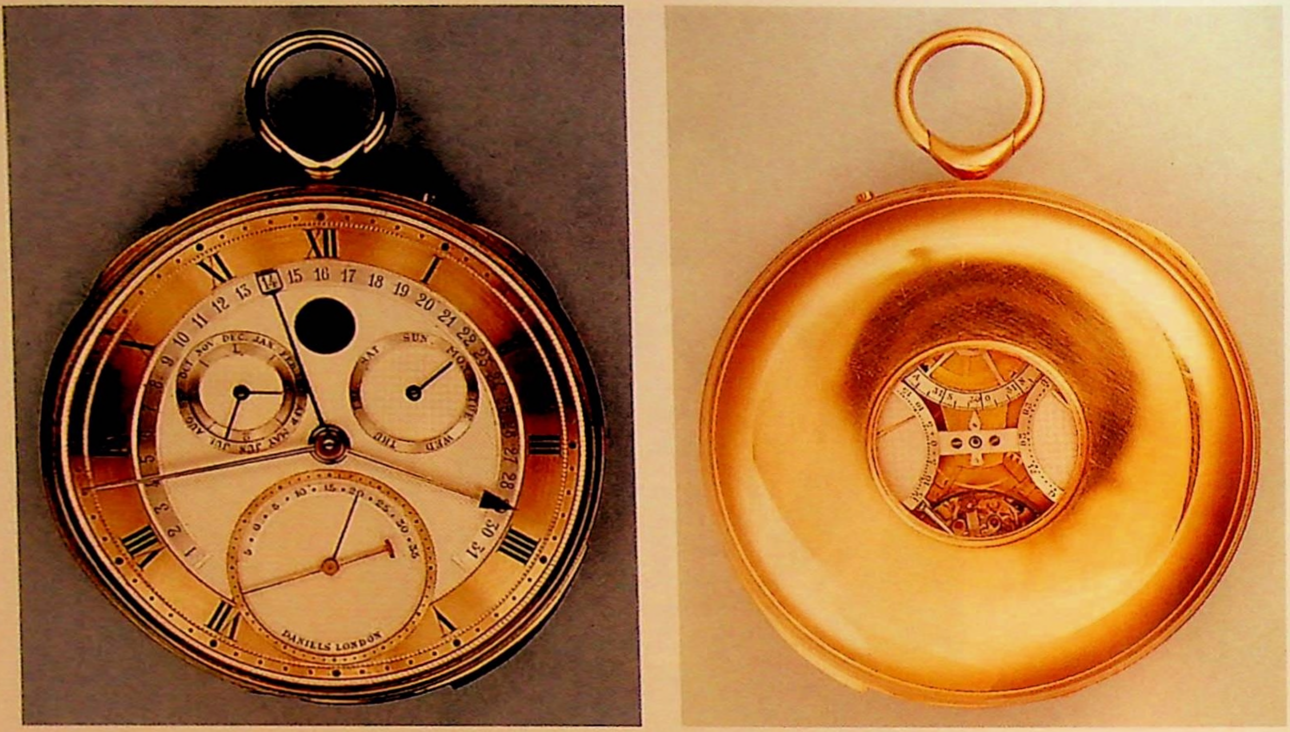
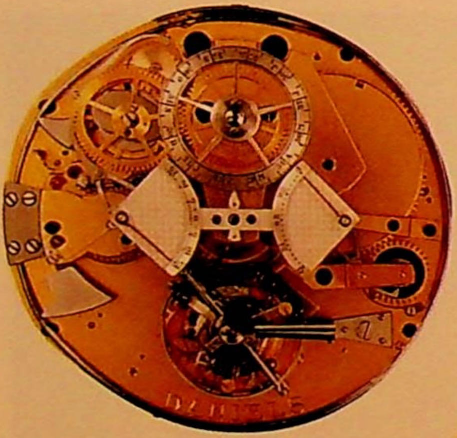


Plate XX



Watch with one-minute *tourbillon* with Daniels co-axial escapement, three-armed balance with eccentric gold adjusting weights, Elinvar spring with terminal curve, minute repeating on two gongs, perpetual calendar with instantaneous change of all functions at midnight, phase of the moon, silver dial with inset gold chapters and seconds, gold hands, silver subsidiary dials for day and month with leap-year indication, centigrade thermometer, the reverse of the gold case with aperture for the equation of time with setting calendar and reserve of winding indicator.



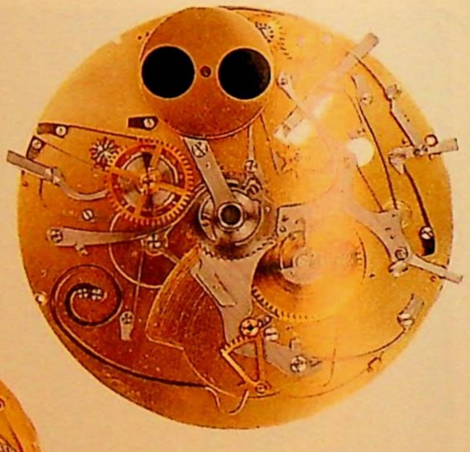
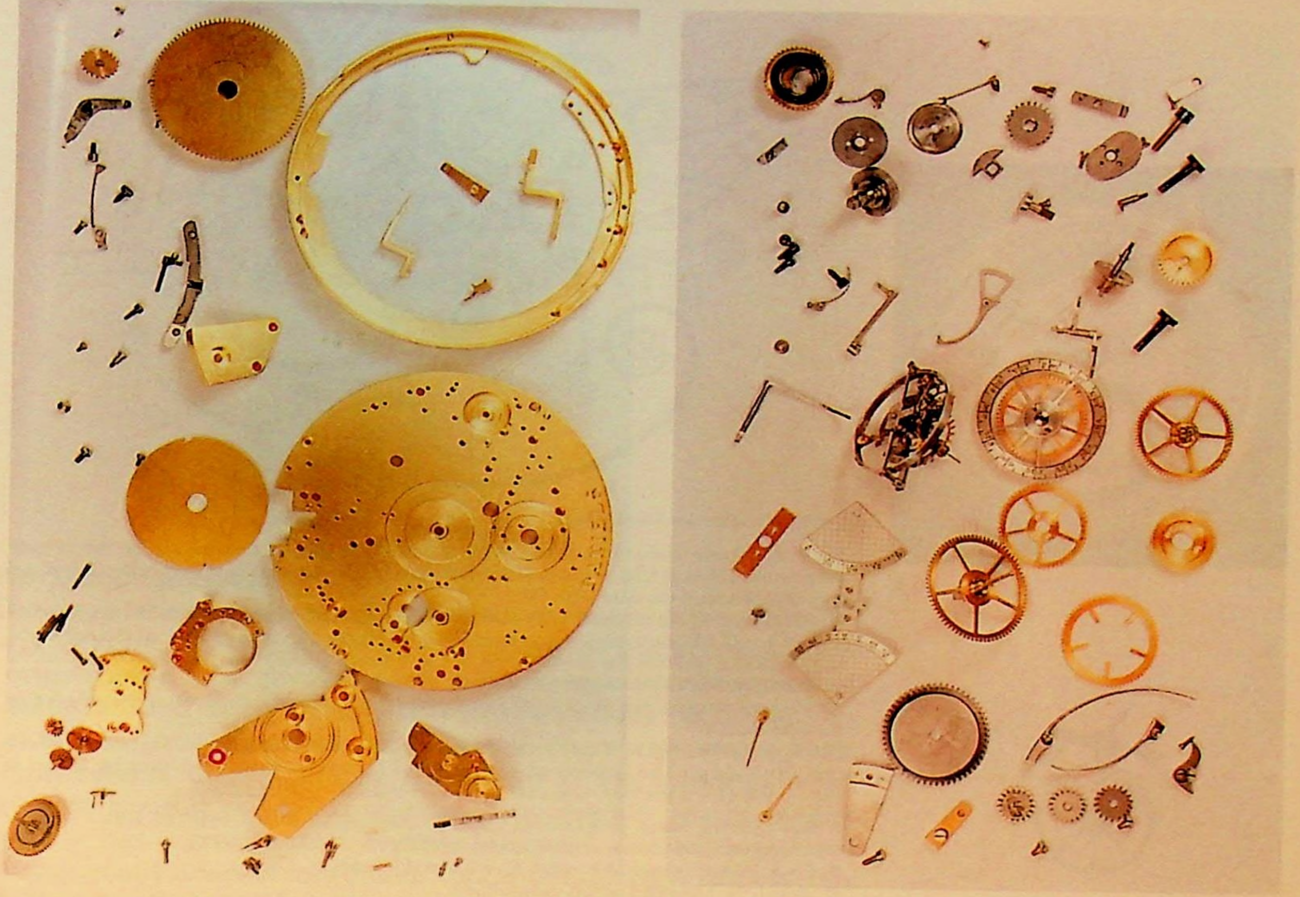


Plate XXI



Components of the watch illustrated in Plate XX.

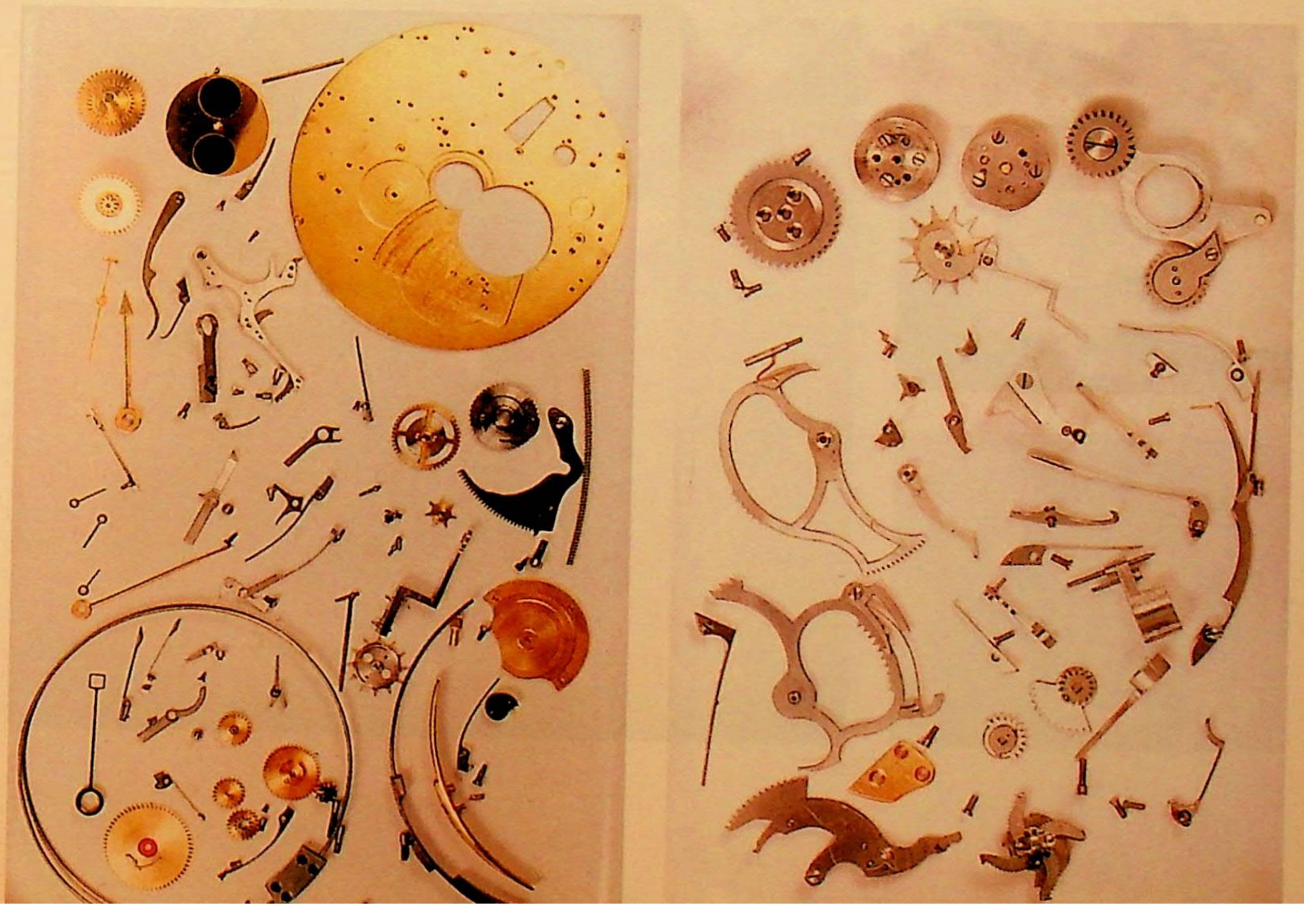
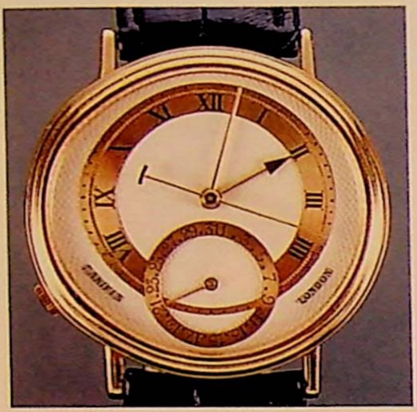
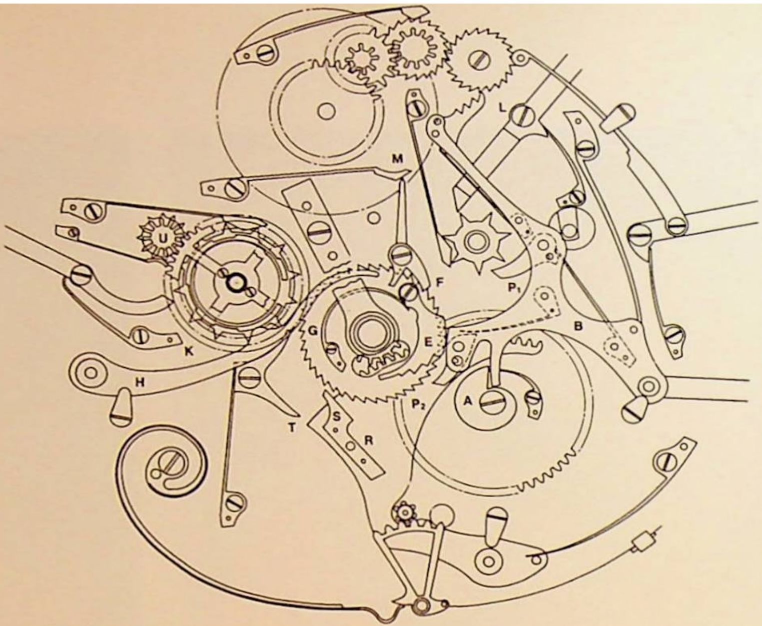


Plate XXII



A



Perpetual Calendar Mechanism

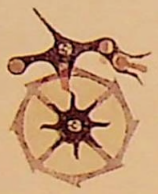
The cam *A* turns once in 24 hours to lift *B* and cause pawl *L* to advance the moon train three teeth. When *B* falls to the position shown it allows pawl P^1 to advance the day wheel and P^2 to advance the date wheel *G*.

Wheel *G* carries the stepped release catch *E*. At the end of each month the appropriate step of *E* will lift aside pawl *F* to allow *G* to be returned to the first day of the month by rack *R*. In this position the pivoted end of *E* will touch the tail of pawl *F* to return it to the gathering position seen as at the first of the month.

As the rack returns, the piece *S* catches the advancing lever *T* to advance the wheel *K* to the next month.

The appropriate step of *E* is selected by the position of *H* riding on the edge of the month cam of wheel *K*. The 12-toothed planet wheel *U* is turned once per year by wheel *K*. Within wheel *K* is the leap-year cam geared 4:1 with the planet pinion.

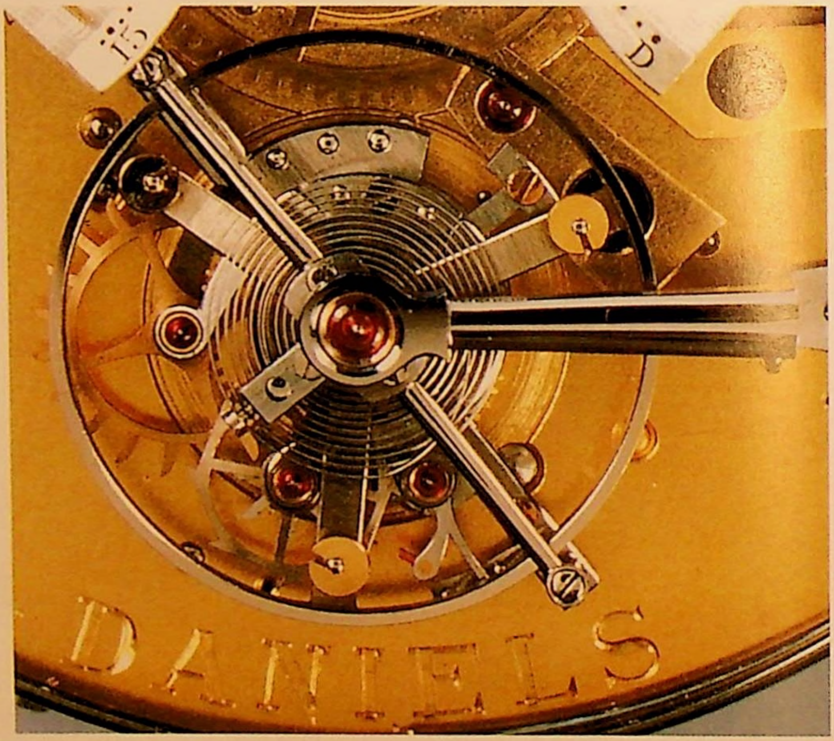
A Self-winding watch with Daniels Co-Axial escapement. Simple calendar with rapid correction. Gold case, silver and gold dial.
B Co-Axial escapement for watch C of 2 mm thickness.
D Zenith 36,000 with Daniels escapement.
E Co-Axial *tourbillon* of watch illustrated in Plate XX



B

C

D



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WORKSHOP AND EQUIPMENT

Workshop Specification

The size of the workshop and general arrangement of its equipment will depend largely on the circumstances of the occupant, but consideration must always be given first to regulations concerning the health and safety of the occupants, especially regarding fire, acids and toxic chemicals. In addition, there are certain basic requirements that should be considered if the workshop is to provide comfort as well as working convenience. The horologist usually has a greater than average interest in his work and can sustain many hours of continuous concentration. Nevertheless, it is still work which, in gloomy surroundings, can eventually become tedious. Low spirits are not conducive to creative work and are a discouragement to the long periods of continuous application usually required in its execution.

A professional horologist will spend approximately one third of his working life in his workshop. If he possesses a spirit that wills him to make a positive contribution to his profession, he will devote even more time to his work. He will find himself drawn to his workshop as often as others in different fields are drawn to their studies, studios and easels. Indeed, he will not regard his occupation as work, but rather more as an enjoyable part of his life. Even so the greater part of his activities will, as in most professions, consist of basic, routine operations directed towards the final and immense satisfaction of the completed work. In order to ease the performance of this routine work it is essential that his surroundings are congenial and comfortable.

The horologist should arrange his workshop as the intelligent woman arranges her house. It should be bright, easy to clean and with all facilities conveniently to hand. The most important thing to be considered is the available natural light. Unfortunately this is also the most difficult to arrange. When horology was a thriving profession, and town and country planning was unheard of, the watchmaker could select a house to suit his requirements and build his workshop against the wall that offered the best light. The lean-to wood and glass structures that once proved so satisfactory are now no longer acceptable to local authorities, who seem more concerned with their interpretation of environmental dignity than with helping aspiring young men to become useful and enterprising members of the community. As a result building costs have become a major factor in the establishment of a new workshop and the horologist may need to adapt himself to existing conditions that are sometimes less than ideal.

The model workshop would be a minimum 15 m long and 5 m wide with large windows at each end facing east and west. The east window would be approximately 3 m square and rise from floor level to admit as much light as possible and at the top would have horizontal louvres for ventilation. The west window would be of similar width but rise from approximately 1 m above floor level. An east-facing skylight would be included for ideal natural lighting conditions. The principal hand-work bench would stand before the east window and the water sinks and wet benches before the west window. The central space could then be filled with various pieces of machinery, and additional benches arranged to suit individual requirements.

It is usually thought that a north-facing light is the best because it is more uniform and produces softer shadows. There are some occasions, especially during the summer months, when a north light is quite adequate for general illumination but for the most part, in Britain, it is too dull to be useful. An east light is brighter on a winter's morning and affords the pleasures of sunrise without the bright heat of a summer's day. The west window will allow the sun to shine into the workshop only at the end of the day. The changing nature and intensity of light throughout the day make a pleasant contrast during working hours.

Precautions should be taken to prevent any inconvenience which might arise from badly positioned workshop windows. A south-facing window would be excellent on a dull day but too hot and bright on a summer's day. In the latter case a venetian blind would deflect much of the heat and light away from the bench. It is not possible to work comfortably at a bench which catches the full light of the sun from the front. Under these conditions the pupil of the eye will close and fine details of work, which will be facing the watchmaker and therefore be in shadow, will not be seen clearly. Such conditions will cause severe headache and eventual deterioration of sight.

If the window is facing north the only inconvenience will be a lack of natural light and this is easily overcome by artificial light. One 2 m fluorescent tube suspended approximately 1.6 m above the centre of the bench will supply adequate general light. And for general lighting throughout the workshop fluorescent tubes are ideal. They can be obtained in varying intensities and colours of light and when fitting out a workshop the advice of a reputable manufacturer will be invaluable. For close work the tungsten lamp in an articulated holder is satisfactory and for convenience every machine and bench should be equipped with one.

The floor of the workshop should, if possible, be constructed in the traditional manner with wood joists and floor-boards. The present trend of constructing floors of reinforced concrete can make working conditions extremely uncomfortable for feet and legs because of its coldness in the worst of the winter. If the watchmaker is so wrapped up in his work that he is not properly aware of his discomfort his health will soon suffer. A further fault with these floors is their extreme hardness. Even with a suitable floor covering to give a smooth, clean surface they are still so hard that small tools will be damaged and Arkansas slips and similar stones will shatter if dropped. But if there is no choice concrete floors can be improved by covering them with wood flooring laid over a suitable insulating material. A final covering of good-quality, light-coloured linoleum will enable fallen components to be heard as they strike the surface, and their resting position to be seen easily.

The height of benches and seats is important if comfort is to be assured during long periods of sitting. The seat should be of hard, polished wood, shaped at the front edge to relieve pressure on the thighs. Four-legged stools are better than three-legged ones and enable the sitter to reach out for more distant tools and equipment without danger of tipping over. A polished seat will allow slight changes in position while working, without shifting the weight of the body on to the feet. Revolving seats are most unsatisfactory and liable to sudden disconcerting shifts of position when pressure is used on hand tools. When seated the thighs should be horizontal and the lower leg vertical. If the foot is now moved forward or backward the knee will be lowered, allowing a change of position during the most concentrated work without having to move the seat. It is tiring to sit for long periods with the thighs sloping up or down from the body while the lower leg is vertical.

The height of the bench will depend on the height of the user. A good guide is to adjust the bench height so that, when sitting upright at the small lathe or turns, the eyeglass is approximately 45° above the centre of the work. This position will allow a clear sight of the work without forward curvature of the spine. For hand work on small components a higher working area is required at the centre of the bench. An eyeglass is always needed for small work and it is better to raise the work to the level of sight rather than to lower the head to the level of work. A rigid foot rail about 20 cm above floor level will allow further changes of seating position while working. The bench surface is best covered with a hard, smooth, light-coloured material. The centre working area should be darker to prevent excessive light reflecting into the eyes when working closely.

The length of the bench is a matter of preference but it should be remembered that, when working on even a small component, as many as twenty or more different small tools may be required and a small bench will soon become cluttered. A useful addition is a sliding catch-tray to hold small tools while working and to catch any small components accidentally dropped. Regularly used small tools can be conveniently kept in a rack at the back of the bench, while the great variety of additional small tools that are needed can be kept in drawers beneath the bench. The arrangement of the small-work benches in my own workshop is illustrated in Plate I.

Drawing Methods

The watchmaker who wishes to improve his work must be able to make precise drawings of new developments before he begins to make the components. Every aspect of a new mechanism must be studied in detail at the design stage if mistakes are to be avoided. The power available to drive the mechanism is limited and maximum efficiency is required to make the best use of it. This is particularly the case when making the escapement, where it is very important to keep power losses to a minimum. The minimum permissible sliding friction, escape-wheel drop, locking angles and lost motion generally are most quickly determined at the drawing board.

It takes only a short time to draw to a large scale two components that are to work together. These can then be pinned to the drawing board at their correct centre distances and their combined actions can be studied in slow motion. It would take many hours' work to make the components first which by then could well be inexact. This method is particularly useful for studying the action of wheel-tooth forms and escapement details.

Make the drawings on smooth, white paper and cut out one to superimpose on the other. Alternatively, the drawings can be made on tracing paper and then one can be viewed through the other. Use a good-quality ruler with a bevelled edge to avoid parallax errors. When measuring off a distance make a pin prick to mark the length. If a line is needed put the point of a hard, sharp lead into the hole and then bring the ruler up to the lead to draw the line. This method is particularly useful when marking off critical angles with a protractor. Use a protractor with a bevelled edge and with full radial lines for the 10° divisions. When several accumulating angles are needed always measure from the first radial to avoid accumulating errors. The watchmaker's prime concern is to draw true diameter circles to scale and divide them into accurate angles. From these the actual dimensions of the components may be found with a good ruler.

When drawing the angles of an escape wheel to engage a component, only the active teeth are required. But to ensure complete accuracy of the required angles all the teeth should be marked off. Do this with a dividing compass, adjusted by trial to walk around the circumference and to return precisely to the starting point. Make a pin prick for each tooth and with a sharp lead in the hole bring up the ruler to draw the radial. This method will ensure precise division of the circle so that drops and clearances can be measured from the drawing with the ruler.

To draw a true diameter circle draw a straight line first on scrap paper. Place the point of the compass on the line and, with a sharp lead, draw small arcs across the line. Measure the diameter and adjust as necessary for a further trial. When satisfied make the circle on the drawing itself.

When centre distances only are required these can be found from the functions of the triangle. In Fig **1**, representing half of the escapement illustrated in Fig **482**, the centre distances of the balance to escape wheel, the escape wheel to detent and the detent to balance wheel are required.

The escape wheel, with 15 teeth, is of 9 mm diameter and therefore $R = 4.5$ mm. $\frac{360^\circ}{15}$ teeth $= 24^\circ$ per tooth with 4° allowed for transfer drop. The escaping angle is 36°.

Angle $aSR = 10^\circ$

Distance $Sa = \mathrm{R}\cos 10^\circ = 4.432$ mm

Distance $Ba = \frac{\tan 10^\circ}{\tan 18^\circ} \times Sa = 0.5427 \times 4.432 = 2.405$ mm

Distance $BS = Ba + Sa = 2.405 + 4.432 = 6.837$ mm

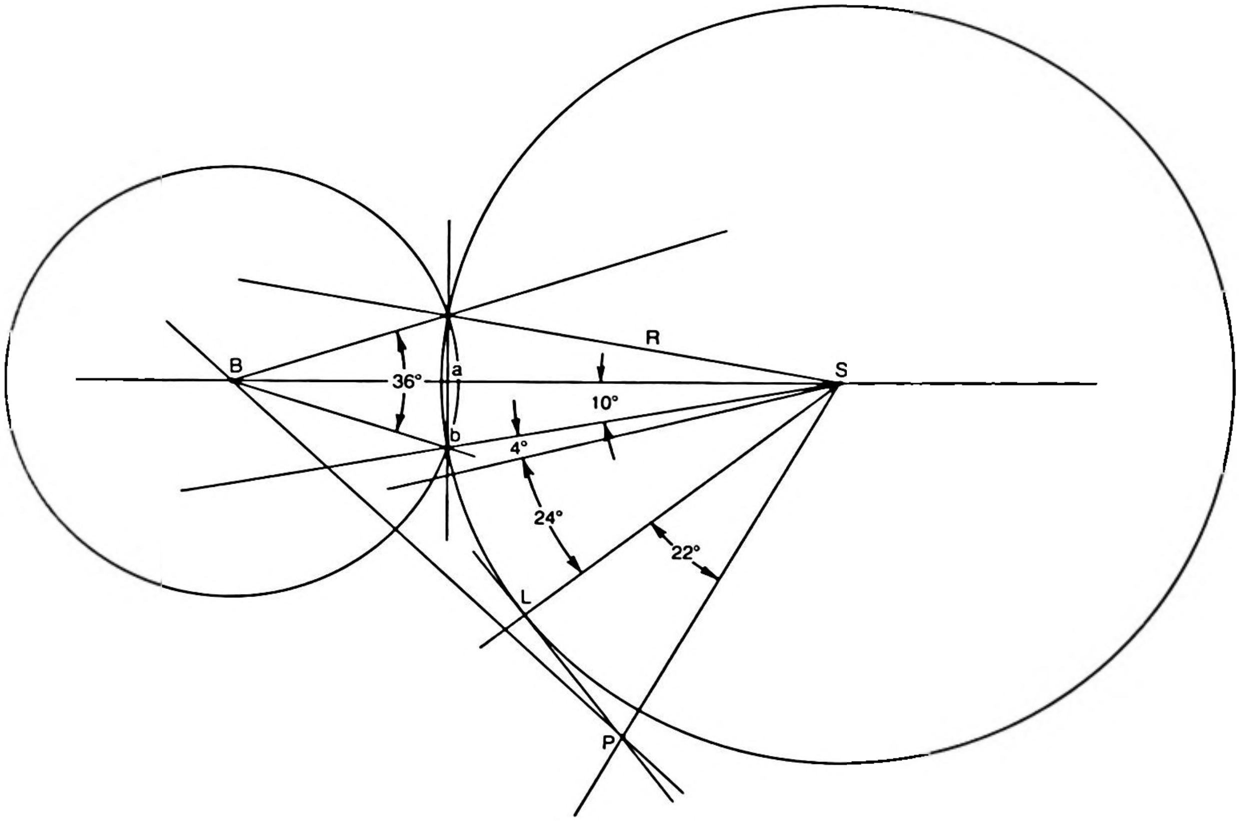
Angle $LSP = 22^\circ$

Distance $PS = \frac{LS}{\cos 22^\circ} = \frac{4.5}{0.9272} = 4.853$ mm

Distance $BP^2 = PS^2 + BS^2 - 2 \times BS \times PS \times \cos BSP = 37.116$ mm

Distance $BP = \sqrt{37.116} = 6.092$ mm

Distance $LP = \tan 22^\circ \times R = 1.818$ mm

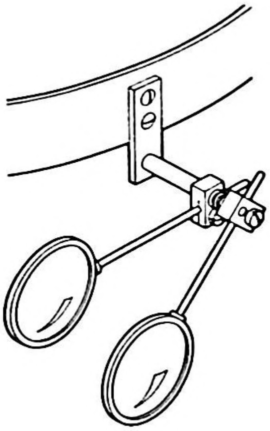


1 Centre distances can be found from the functions of the triangle

Visual Aids

The quality of the watchmaker's sight is of paramount importance. Uncorrected defects of vision will cause headaches and fatigue and lead to poor-quality work. For general bench work, a 10 cm focal-length glass is quite adequate. A shorter focal length would force the head to be held unnecessarily close to the bench, with resultant loss of perspective and insufficient distance between the glass and the work to allow freedom of manipulation of tools. Long focal-length lenses are not readily available but can be obtained, made to order, from an optician. Have them made to fit a standard-sized eyeglass holder or a frame for use with spectacles. For closer work a 5 cm glass will suffice for all but the smallest details. There are occasions when a stronger glass is necessary as, for example, when turning very small pivots. For this work the watchmaker must choose a glass that enables him to see clearly without having to get unnecessarily close to the work. It should be noted that the stronger the glass the greater is the concentration necessary to focus the eye.

The inconvenience of changing an eyeglass for one of a different focal length can be overcome by fitting two single lenses to a common centre and swinging them into use either separately or together. If they are of 10 cm and 5 cm focal lengths respectively, they will be adequate for all general purposes and when combined will be sufficiently strong for very close work, see Fig **2**. However, their effect on the focal length of the eyeglass must be taken into consideration if spectacles are worn. The swivelling eyeglass combinations are easily fitted to spectacle frames or to a band fitting round the head. These combination lenses are best mounted to the bridge of spectacles, or in the centre of the forehead if fitted to a band, to avoid obstructing the hand when working closely.


2 Three focal lengths are obtainable from two lenses

For examining wheel depths, pivot finishes, escapement actions and working clearances, etc., a binocular stereo microscope of 10 × and/or 20 × magnification is a tremendous asset. These instruments include illumination that can be finely directed and this, combined with the three-dimensional image, enables a most detailed examination to be undertaken without excessive concentration.

The Lathe

The lathe is the most versatile of the machine tools used by the watchmaker. With the various accessories available it can be used for live turning; dead-centre turning; uprighting; grinding; lapping; milling; slitting; dividing, including wheel cutting; and polishing.

In its present form the lathe was devised in the late nineteenth century at a time when hand watchmaking still flourished and was a busy industry. It was developed principally by the Americans for the production and finishing of complete watches in their factories. The English watchmaker had little use for the lathe. His main work was accomplished by turning arbors and staffs for escapements which he bought from specialist suppliers. The work was done in the turns with a handbow. Because he was very skilled with the turns, and had little or no experience of the lathe, he encouraged the belief that the lathe was inferior to the turns. This belief is still sometimes held today and is fostered largely by those who have done bad work as a result of using old and worn equipment, without a proper understanding of its use.

The principal aid to the truth of turning in the turns is that the work revolves in dead centres and so can be turned end for end without becoming eccentric. With the standard accessories available for the headstock and tailstock of the watchmaker's lathe, the same technique can be used but with the advantage that the work can be revolved at a much higher speed and in a constant direction. This enables the work to be accomplished more quickly than would be possible in the turns, and the speed of working can be further improved by controlling the direction of cut with one hand, while the other hand is used only for presenting the graver to the work and resisting the cutting pressures.

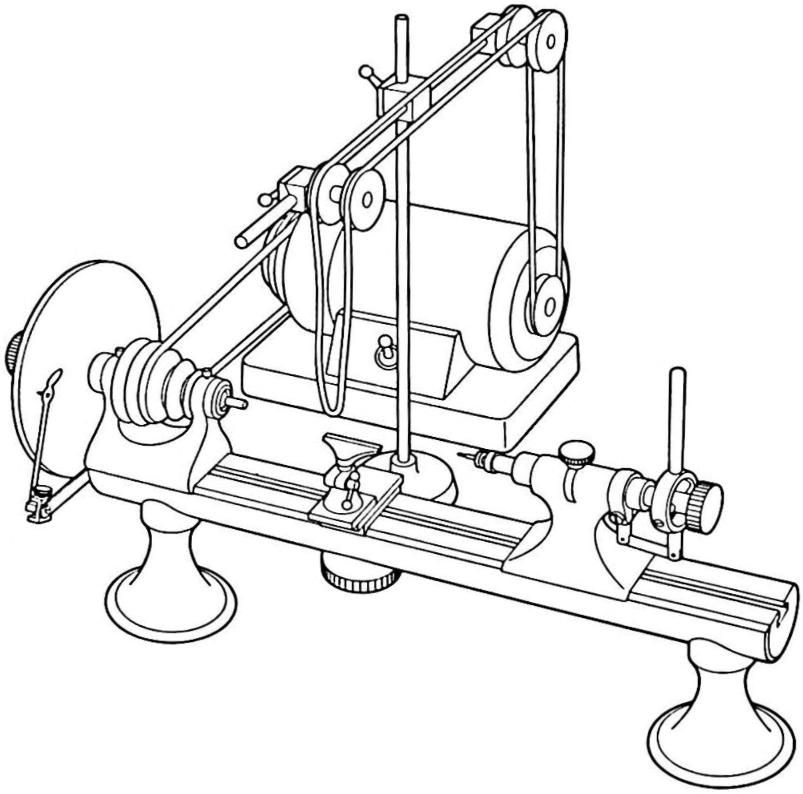
In addition the work can be gripped in the collets of the headstock, the mandrel face plate with dogs or in a variety of detachable chucks especially designed for holding the great variety of work done by the watchmaker. The work can be turned in a chuck almost to size and then for ultimate concentricity finished between dead centres. Alternatively it can be turned and finished without using centres. The various methods are all illustrated as appropriate to the work described.

For polishing, the turns are said to be better for producing a rich black polish to arbors, etc., because of the to and fro motion of the work produced by the bow. This is quite untrue and to subscribe to this view is to admit to an imperfect understanding of the technique of polishing arbors.

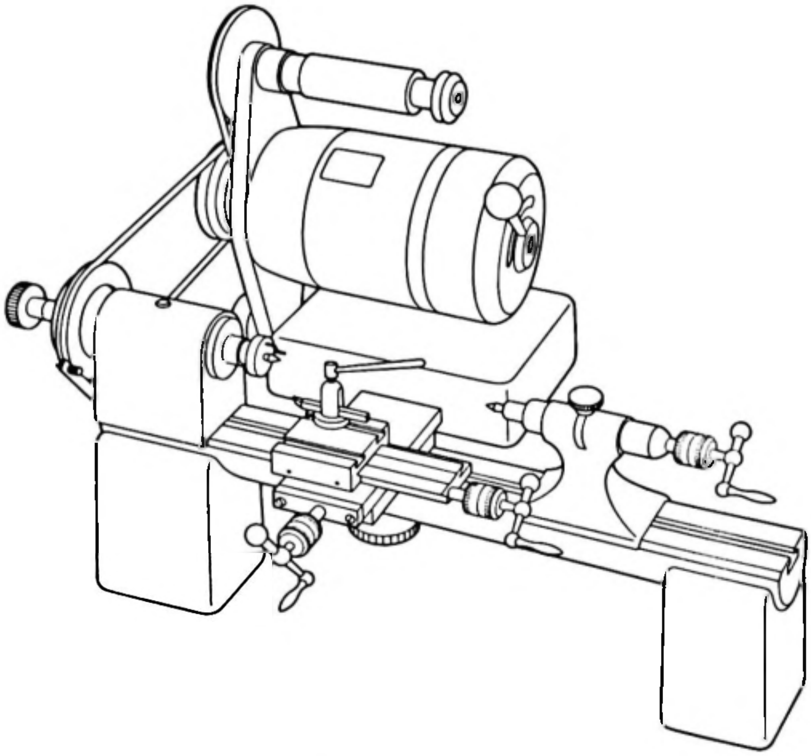
There are times when the nature of the work is so delicate that the use of a bow is most helpful for the control and delicacy it offers in rotating the work. This is especially so when finishing pivots, adjusting the lengths of arbors and topping escape wheels, etc. This work could be done in dead centres in the lathe but, with specially adapted runners, the turns are more convenient. These, too, are illustrated as appropriate to the work described.

Lathe Types

The use of the lathe during the past thirty years has declined, largely as a result of the ready availability of interchangeable parts for machine-made watches. As a result of this, the number of manufacturers has fallen, but because the design of the lathes has changed very little since the beginning of this century, the range of choice remains much the same. The choice of lathe is important. There are two basic types which differ principally in the form of bed. One is in the form of a ground bar, about 25 mm in diameter, with a flat machined along its length to align the various components. The other is much heavier, with a flat surface and angled guides to align the components. This form, illustrated in Figs 3 and 4, has much greater rigidity and offers greater accuracy of alignment of the components so that it is altogether better suited to watchmaking.



3 8 mm lathe with plain bearings and overhead drive for the milling quill



4 8 mm lathe with ball-bearing headstock and slide rest

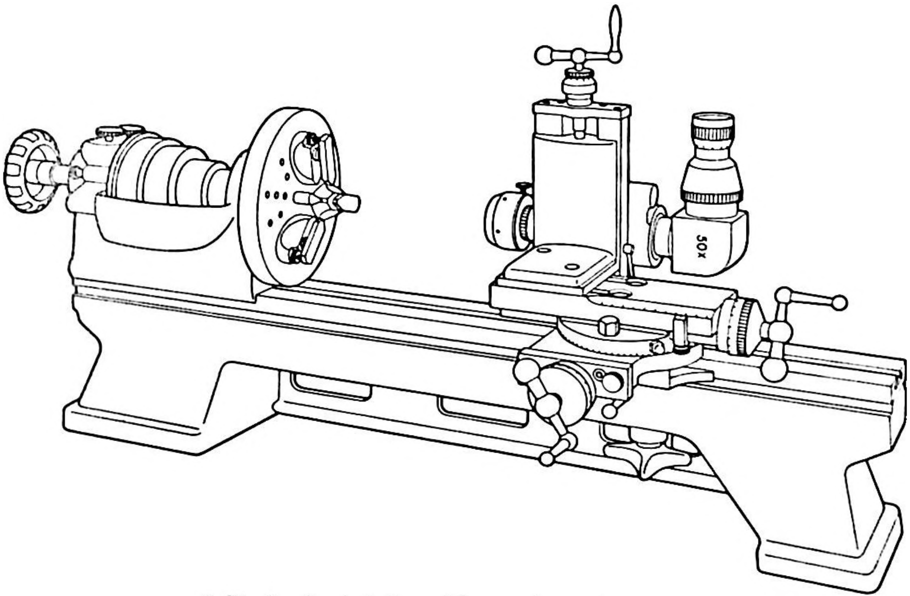
The headstock spindle has a through bore of 8 mm to take collets and a variety of different chucks. Some spindles run in ball-bearings, as in Fig 4, and others in ground, double-cone plain bearings, as in Fig 3. Generally speaking, ball-bearing spindles offer greater sensitivity of touch to the fingers when the spindle is rotated by hand, as when threading fine arbors, etc. The most useful accessories for the headstock are illustrated as appropriate to the work in hand.

Accessories for the bed include the slide rest, with thimbles graduated in hundredths of a millimetre, a pivoted 'T' rest that can be tipped away from the work without altering the clamping nut, a tailstock with runners to take drill pads, sinkers, pivot-polishing equipment, and a drilling tailstock to take the 8 mm collets of the headstock. These also are illustrated as required.

The pulley of the headstock usually has one or more rows of holes for simple dividing, but for more complex divisions a dividing plate can be fitted to the headstock spindle. The index for this is usually a point set in a leaf spring. This arrangement allows only for indexing the work by whole divisions, and it is sometimes necessary to advance the work by part of a division as, for example, when thinning the teeth of a wheel. The index shown in Fig 3 allows this facility by adjustment of the height of the point. An overhead drive will be required for milling and grinding accessories, and Fig 3 includes a suggested arrangement that will be flexible enough for all requirements.

Toolmaker's Lathe

The complete watchmaker will need a heavier lathe for general workshop use. An increase of centre height to 70 mm or more will allow cases, plates, wheels, pinions, etc., in addition to the great variety of general turning, to be accomplished with ease and speed. Fig 5 shows a typical machine described as a toolmaker's lathe. It



5 Toolmaker's lathe with centring microscope

can be fitted with a variety of equipment to perform all the tasks of the watchmaker's lathe but to a greater scale.

Tolerances

A good-quality lathe, when purchased new, will be accompanied by a certificate giving the maximum allowable tolerances of concentricity and parallelism of the headstock spindle and bed accessories. The actual measured errors are also recorded in the certificate, and for a good-quality lathe these figures will be very small. Most manufacturers are prepared to accept a maximum allowable eccentricity of 0.005 mm; this is a very small amount, but the actual error in the spindle will usually be less than half this figure. The collets also will have a small manufacturing tolerance; for the best-quality, selected collets this eccentricity will be very small and, combined with the eccentricity of the headstock, will produce a total error of less than 0.01 mm. This is quite acceptable for the majority of watchwork and where it is not the work can be turned between dead centres.

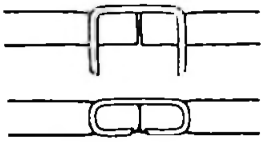
Drive Control

The most convenient form of drive for the lathe is by electric motor with variable-speed foot control. The advantage of this is that the maximum speed required can be set on the motor control, and variations up to the predetermined maximum speed selected by the foot control. With this arrangement the point of the graver can be presented to the work with critical accuracy for positioning corners or sinks with the work stationary or revolving slowly. The predetermined maximum speed-setting of the motor will preserve the cutting edges of the graver from the effects of excessively high peripheral speeds.

The speed of rotation will depend on the diameter of the work and the skill of the turner. As a general guide, when turning blued steel of about 1 mm diameter, a speed of some 2,000 rpm would suit. For larger diameters reduce the speed by proportion to about 800 rpm for 3 mm diameter. Higher speeds will wear the cutter and glaze the work so that the cutting will be slower and uneven. For very small diameter work of less than about 0.7 mm, higher speeds are not harmful but if the point of the graver is used it is better to keep the speed to about 3,000 rpm.

Belting

Some makers supply endless elastic belts for the lathe drive. These are satisfactory when the loading is light and the belt short. For long belts, which are necessary for overhead drives to drilling and cutting quills, leather will produce a steadier drive. Cut the belt to length and join the ends with a brass staple as illustrated in Fig 6.



6 Wire link for leather drive belt

Lathe Cutters and Gravers

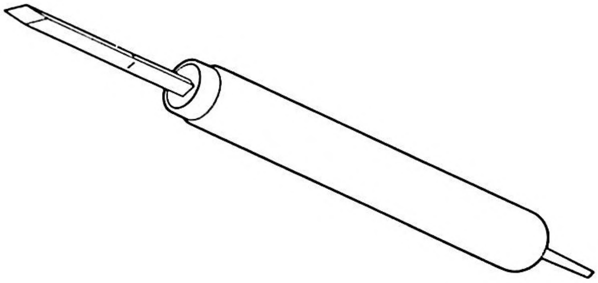
Hand gravers and slide-rest cutters are usually made of carbon steel, but high-speed steel varieties are also available. The principal advantage of the high-speed steel cutter is in its constant hardness throughout its length and its ability to withstand heat and high pressure without the hardness deteriorating. For the watchmaker, its disadvantage is in its inability to keep a sharp edge when used for turning hardened and tempered steel. In particular, watchmakers frequently require very sharp-pointed gravers for forming square corners, and for this work the point of a high-speed steel graver would soon become rounded, causing the work to glaze and increase the difficulty of turning.

It is frequently said by watchmakers that one can no longer obtain carbon-steel gravers of the quality used by the hand watch-finishers of old. This probably accounts for the increasing use of high-speed steel substitutes. Undoubtedly there is a decline in the number of manufacturers of carbon-steel gravers as a result of the decline of hand watchmaking. Consequently those who still require high-quality gravers have a more limited choice and are therefore likely to be disappointed. On the other hand, the watchmakers of old used the turns and rotated the work with a bow. This method is slower than turning in the lathe and inevitably does not work the graver so hard. It is probable that imperfect sharpening of the graver also contributes to the belief that the steel is inferior.

With a correctly sharpened graver it is necessary only to apply the very lightest pressure to the graver to maintain it in contact with the work. The cutting must be done by the sharpness of the edge and not by pressing the tool against the work.

Preparing a Graver

If good-quality, carbon-steel gravers cannot be purchased, they can be made from modern high-grade tool steel. This can be purchased from tool shops in lengths, varying in size and shape, suitable for watchmakers' gravers. Prepare a length of about 150 mm by 2 mm square by filing the surfaces smooth until the edges are quite clean and square. File the cutting edge as shown in Fig 7. Make a shallow nick with a file about 40 mm from the top of the cutting edge. Heat the steel to a bright red and plunge into thin, cutting oil. The graver will now be hard enough to be used for cutting hardened and tempered steel with ease, and can be continually resharpened until the notch is reached, when it will be necessary to harden a further 40 mm or more for further use. Unless special hardening equipment



7 Hand graver for lathe or turns

is available, it is useless to attempt to harden the whole length of the graver at one time.

Sharpening the Graver

Fit the graver, friction tight, into a long, wooden handle drilled all the way through. This will enable the graver to be kept at constant length by drawing it from the wood as it is worn down by sharpening. Sharpen on an oilstone until the angled surface is a flat, regular-shaped diamond. Do not attempt to hurry the sharpening but move the graver with long, regular strokes over the whole area of the stone. Any loss of contact between the full area of the diamond and the stone will be felt as a reduction in friction and result in a rounding of the surface of the diamond. This will cause curvature of the cutting edges and make the graver less effective for producing straight arbors.

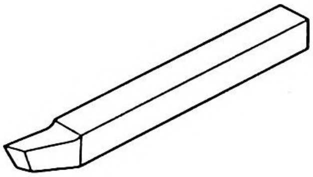
Producing an absolutely flat and regular-shaped diamond face is the first principle of turning and it is vitally important that the technique be mastered, for it will make the tool easier to use. When satisfied with the sharpening, remove the burrs from the edges by laying the flat surface of the graver on the oilstone, and with a light pressure make one sweep to the end of the stone and back for each surface. Do not tip the cutting edge into contact with the stone during the deburring for this will make the point more obtuse and reduce the effectiveness of the graver.

Some authorities favour the use of Arkansas stone for finishing the sharpening, but unless it is a very high-grade stone with a good cutting surface, it is likely to do more harm than good by requiring excessive pressure which will put the diamond out of flat and raise more burrs at the edge. It is better instead to draw the two cutting edges of the graver gently across a piece of soft wood covered with a paste of crushed water-of-Ayr stone and thin oil. This will completely remove the fine rag burr left from the deburring on the oilstone and leave the edges clean and sharp. If, after this treatment, the edges are examined under a bright light with an eyeglass, they will reflect a fine, almost imperceptible glint, which is in fact an immeasurably small radius. This will in no way affect the keenness of the edge, but will protect it from crumbling when in contact with particles of hard steel rag which could be carried round during initial contact with the work if not removed first. A graver sharpened in this way will cut keenly with long, curling swarf and leave a bright, smooth surface requiring almost no attention from the oilstone polisher before final polishing with diamantine.

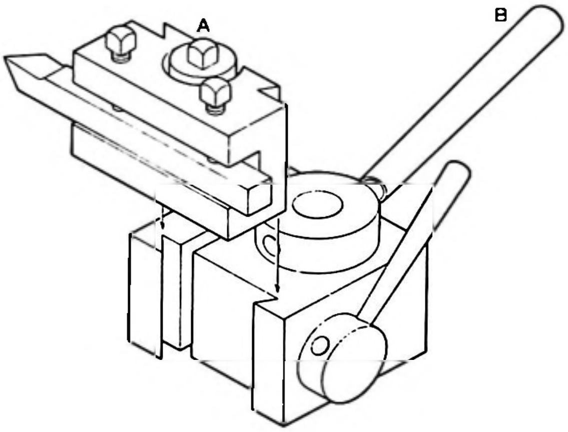
The diamond face of the graver can be elongated by the use of a lozenge-shaped steel instead of the usual square-section steel. This is useful when especially deep sinks are needed for pinion faces or balance-staff rivets, etc.

Slide-Rest Cutters

Carbon-steel cutters and high-speed cutters are equally effective when used in a slide rest for turning annealed steel. The watchmaker does not often use the slide rest for turning hardened and tempered steel, but when it is necessary the tip of the tool should be radiused, as shown in Fig 158, to resist the increased pressures and prevent the work glazing from a worn cutter point. If sharp corners are necessary to the work, then the cutter should be sharpened to a point, when the turning is almost complete, and a final, light, finishing cut made over the whole surface. Alternatively, the slide rest can be removed and the corners sharpened with a graver resting on the 'T' rest. Annealed steel will turn more freely if the top surface of the cutter is raked back to about 10°, as shown in Fig 8.

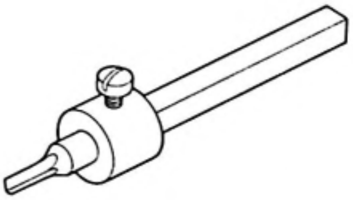

8 Slide-rest cutter

Again, when turning brass, either carbon-steel cutters or high-speed steel cutters may be used. The top rake is not necessary with brass, but this is not important and so the same cutters may be used for both materials. The tools are clamped to the slide rest in a tool post that usually has an arrangement for setting the height of the point to the centre of the mandrel. With this method, the centre height must be reset each time the tool is replaced after sharpening. A better system is illustrated in Fig 9 where the tool is clamped into the holder with adjustment for centre height by the screw *A*. The clamp is released by lever *B* and the block, complete with tool, is removed for sharpening. Screw *A* will ensure its replacement at the original setting.



9 Tool holder with adjustable centre height

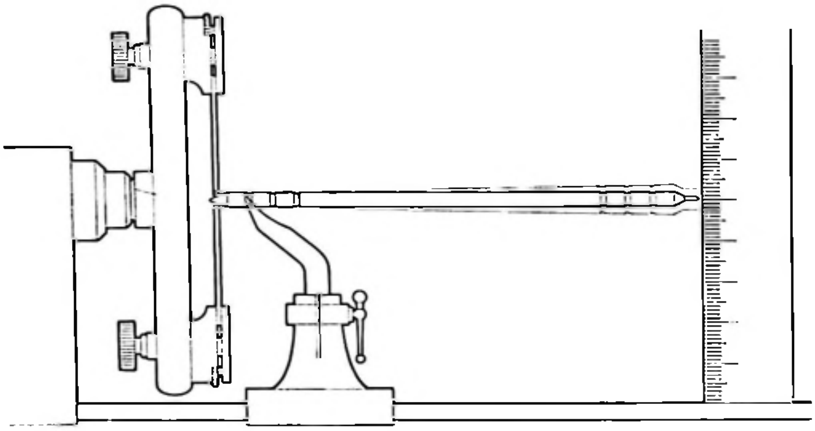
The boring-tool holder, shown in Fig 10, will take a variety of differently sized cutters from a standard diameter, tool-steel rod. Turn the steel to the maximum required width of cutter, file to a half-round form, and relieve the curve behind the cutting edge.


10 Slide-rest boring tool

Centring in the Lathe

When using the mandrel plate with dogs for uprighting holes or turning recesses the work must be truly centred. The pump centre of the plate is useful for locating the work but cannot be relied upon to centre precisely. When opening a hole for a jewel to be fitted, or drilling a bridge for alignment with a lower hole, absolute concentricity is necessary to ensure the fitted component is upright. For example, a barrel of 24 mm diameter is to be fitted beneath a bridge 4 mm high and with 0.2 mm clearance. If the bridge is bored only 0.02 mm out of upright, the barrel will have 0.14 mm clearance on one side and 0.26 mm clearance, almost double, on the opposite side. This would look very unsightly and, if the error were repeated in the centre wheel, the two would probably touch. There is no room for any tolerance in uprighting if the watch is not to become unnecessarily thick.

The two accurate methods of centring the plate involve the use of the microscope, illustrated in Fig 5, and the wobble stick, illustrated in Fig 11. For both methods the work is rough-centred on the mandrel plate and finally tapped true with a wood or fibre mallet. Familiarity with the weight of the mallet plays a part in the facility that can be developed to tap the plate concentric.



11 Centring with the steel wobble stick

Microscopes

The microscope can show exactly in which direction to tap the work but it also needs to be centred on the mandrel as the work approaches concentricity. Microscopes usually include a graticule to show the dimension of error but this demands accurate alignment of the lens axis with the mandrel. When the work is correctly centred the microscope can be withdrawn and a drilling quill with draw bar fitted on the same axis. Fit the bridge or cock to be drilled upright. If it is flexible fit a support beneath to prevent movement from the cutting pressure. After drilling, the hole can be opened to the required diameter using a boring cutter in the slide rest. The completed hole will be perfectly aligned with the plate hole.

When a duplicate boring quill is available the drilled hole can be opened to size with a single pass of a pre-set boring tool. It is unwise to interchange the drill and boring tool in a draw bar quill unless a trial hole can be bored to check the diameter. Without duplicate equipment the process is laborious due to the need to dismount the quill holder to allow use of the slide rest for boring.

The method is better suited for work larger than watch size, especially when it is done standing at the lathe. The equipment can be successfully used for measuring and pointing.

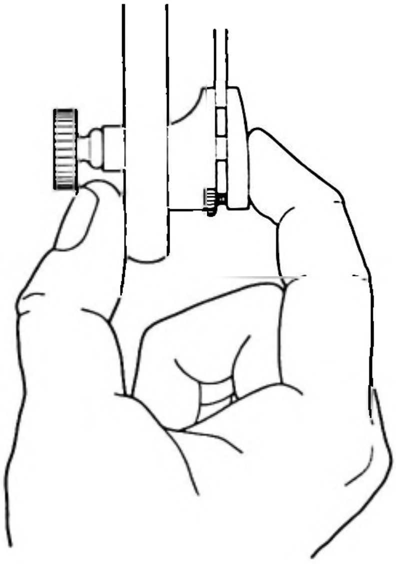
Wobble Stick

For watch work, the wobble stick is quite satisfactory and offers flexibility and speed in setting the work so that it is concentric. A wobble stick is usually described as a piece of peg-wood sharpened to a point to enter the hole to be trued, and supported on a 'T' rest. This may suit a jobber but the watchmaker will need something more durable.

Make the stick from steel rod, 3 mm diameter, pointed at each end to an angle of about 50°. Reduce one end to 1 mm diameter to enable it to reach through small holes. Groove both ends with 15° tapers to rest in a forked support that will slide on to the 'T' rest clamp screw. Cut the grooves at 10 mm, 20 mm and 30 mm intervals from the points and polish the tapers. Finish the rod to 210 mm in length. The principal grooves are at the 10 mm mark. The others are useful when the rest cannot be brought close to the work.

The weight of the rod combined with the angles of the points and grooves will ensure close contact with the hole to be trued, without causing damage to the delicate edge of a small hole. Set the rod slightly high so that it falls towards the hole. Adjust the height of the rest so that a tailstock runner can be set beneath the rod. The reflection of the rod in the surface of the runner will exaggerate the movement of the point. Turn the mandrel slowly by hand and watch the point rise and fall. When it reaches the maximum low position tap the work at the top and check the effect while rotating the mandrel.

Keep the mandrel dogs lightly clamped on the work with the same pressure on each. When the hole is concentric, and no movement can be seen at the free point, tighten the dog clamping nuts while squeezing the dogs to the plate with forefinger and thumb, as shown in Fig 12. Re-check the concentricity and make any necessary final correction. Bore the hole to size using a plug gauge to check the diameter. Fit the bridge or cock and drill and bore to size. It will be quite upright with the lower hole.



12 Setting the height of the supporting nut

Tolerance of Eccentricity

The ratio of length of rod to distance of first groove is 20:1. This is useful to know when absolute concentricity is not required. It is not necessary to spend time making a recess concentric if it is required only to give freedom to an irregularly shaped component. For this purpose make a chamfer where the centre of the recess is to be and centre the plate with the tailstock runner. Fit up the stick with a point in the chamfer and, with a ruler resting on the lathe bed, measure the movement of the free point. The measurement divided by twenty will give the eccentricity of the plate. A movement of 2 mm will represent an error of 0.1 mm and as this is of no consequence to the work in hand, much time can be saved by leaving it uncorrected without anxiety.

Fitting the Work to the Mandrel

Note that the heel of the dogs has a screw with a knurled nut to prevent the clamp tipping with the pressure of the clamping nut. The nuts must be correctly adjusted if the work is to be held firmly and without bruising. Rest the work evenly on the three dogs and slide them into position to allow the pump centre or tailstock centre to locate the hole to be centred. Press down the clamp, as shown in Fig 12, and turn the knurled supporting nut to contact the underside of the clamp. Now lightly tighten the clamping nut. Adjust the other two clamps in the same way. By this method all three clamps will exert the same holding pressure on the work which will then be the more easily centred.

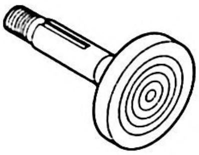
Step Chucks

Step chucks are available for gripping by internal expansion, see Fig 767, or external contraction, see Fig 550. They are not recommended for work requiring absolute concentricity but can be useful for ordinary work.

The chucks should be checked for truth before use. Grip a disc in the internal chucks to give a positive location in the headstock spindle mouth. With a sharp cutter in the slide rest, take a cut from the edge and from the seat of the step required for use. The step should be turned to fit the component so that only a very light pressure on the draw bar will grip firmly and true. External chucks need containing with a ring while turning to fit the inside diameter of the component.

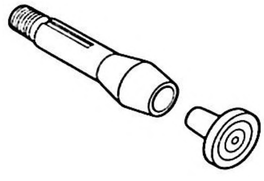
Wax Chucks

There are basically two types of wax chuck, although anything revolved in the lathe and to which the work can be cemented could be called a wax chuck. The most common type have shanks to fit the headstock spindle and are fixed by the draw bar, as illustrated in Fig 13. They are heavy and require a lot of heat especially when fitted in the spindle, for most of the heat will run into the headstock. The method of use usually recommended is to hold the spirit lamp up to the revolving chuck while the component is trued by catching the centre with a point. Flat contact with the chuck cannot be relied upon and, since most components need turning relative to the periphery, the method has little to commend it to the watchmaker. The chucks can be useful if used differently. First try the fit in the headstock spindle. This is usually slack. If any movement can be detected by rocking the flange, the fit must be improved. Lightly burr the shank with a centre punch until it is oversized. Reduce the burrs gradually with the burnisher until the shank is a close fit requiring a light pressure to enter the spindle. Tighten the draw bar and true the face and edge with the slide-rest cutter. Drill a hole through the centre to take a brass peg.

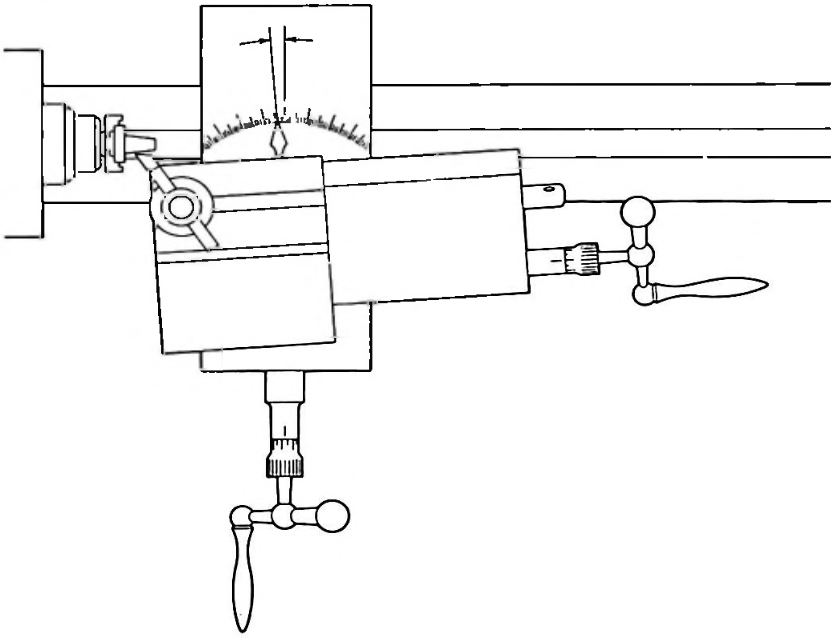

13 Wax chuck for lathe spindle

To use the chuck, turn the peg to fit the centre hole of the component. Remove from the lathe, apply heat and shellac, place the component in position and hold in flat contact while cooling. When returned to the lathe the component will be true and flat. If it is necessary to true the hole of the component, knock the centre pin out from the back. Turn a recess to fit the periphery of the component. Cement and hold in flat contact as before.

A tapered fitting chuck is easier to use for small components. The chuck is fitted into a holder with shank to fit the headstock spindle, as shown in Fig 14. Ensure the close fit of the shank as described above. Fit the chuck into a step chuck and set the slide rest to the same taper, as shown in Fig 15. Take a fine cut from the taper and prepare further chucks of different sizes in the same way.

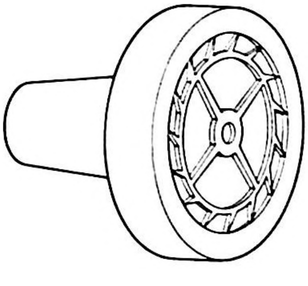


14 Wax chuck with tapered shank



15 Slide rest set for taper turning

Fit the holder to the headstock and with cutter and headstock rotation reversed take a light cut from the internal taper. Both tapers will now be equal and the holder will be true with the shank. Use the chucks with the centre peg or a recess, as with solid chucks, but detach the chuck from the holder which remains in the lathe. Mark both chuck and holder to ensure a constant orientation. The chucks are especially useful for centring escape wheels, as shown in Fig 16.



16 Escape wheel fitted to wax chuck

To remove the shellac put the component in a shallow vessel of methylated spirits held over a spirit lamp. It is not necessary to boil the spirit. Heat until the spirit hisses in the vessel. Maintain a constant heat by raising the vessel higher above the flame. If the vapour ignites put the container down on the bench and then cover with a lid to exclude air. Do not attempt to cover the vessel while still holding it in the hand; it may upset and cause a fire.

Steel

Carbon steel in sheet and rod or wire form can be bought from material suppliers and tool shops. When the steel is to be cut to shape, and drilled, threaded or filed, it must be in the annealed condition. It is afterwards hardened and tempered according to the use to which it is to be put. The hardening temperature and the method of quenching to cool will depend upon the carbon content of the steel. If the makers' instructions are not available it is always prudent to gain experience by experiment before making the components.

Annealed steel is not necessarily soft and lacking in strength. It can be obtained in drawn or rolled form when it will be partially work hardened. In this form it will not resist cutting with saw, file or drill and will not be noticeably harder to work with. For very delicate components such as long, centre-seconds hands, it is a help to the beginner to increase the stiffness of the metal by hammer hardening.

To anneal heat-hardened steel or soften hammered steel, raise to dull red heat and allow to cool slowly. Some steels become completely annealed only if quenched in water before becoming cold. Always obtain the makers' advice on heat treatment if at all possible.

Carbon steels which are described as free cutting are available for quantity production of turned components. These have the addition of an agent, usually lead, to reduce the cutting swarf to powder or chip form. Such steels are especially useful for pinions where the depth of the leaf produces high cutting pressures which can cause chatter. High-pressure coolant is necessary to prevent the chips clogging the cutter if the potentially high cutting speed is used. For individual components a slow cutting speed without coolant may be more convenient.

A carbon content of between 1 per cent and 1.5 per cent will harden if quenched in oil at red heat. A lower carbon content may need a higher temperature and quenching in water. However, this treatment is likely to cause the component to warp if it is an irregular shape. Oil-hardening steels are easier to control but may not polish or blue so well. A steel which contains additives to enhance its hardening properties should be tested first by completing the heat treatment and finishing stages so that their effects may be fully understood.

Steel hardened and tempered to a blue colour will turn smoothly and cleanly with a hand graver. Balance staffs, arbors and pins, etc., are better made from blued steel which can be bought from material shops. With a sharp graver it should produce continuous curling swarf to leave a bright, smooth finish. If the swarf is in short lengths or chips and the turned surface is dull then the steel is probably too soft. It can be hardened by reheating to red and quenching. Temper to suit the work in hand by applying heat.

Carbon steels are obtainable for mass production and hardening of small components to ensure their uniformity, especially in the finished temper. These require exact adherence to the makers' specification for heat treatment if decarburization is to be avoided.

Brass

The most common type of brass used for watchmaking is an alloy of 60 per cent copper and 40 per cent zinc, which is yellow in colour and can be cut, drilled and threaded, etc., with ease. It can be bought in hard-rolled sheet or strip form. In these conditions the stresses introduced by rolling will cause bowing or warping if the surface is machined, as for example when preparing the surfaces of a watch plate. However, the stresses can be relieved by heating to 400 °C for thirty minutes and allowing to cool slowly. The heat will reduce the hardness induced by the rolling but the metal will remain hard enough for the watchmaker. The slow rate of cooling will prevent further softening, which will occur if the hot metal is quenched, and, by precipitation, will reintroduce some of the lost hardness.

Where possible the material for wheels should be obtained in the correct thickness. These are best made from the hard-rolled metal, which will warp to cause unequal thickness of the blank if the surface is machined to reduce the thickness. The addition of up to 1.6 per cent of lead will help reduce burrs and produce a better finish from the cutter. The alloy most commonly recommended is in the order of 60 per cent copper, 38.4 per cent zinc and 1.6 per cent lead.

It is sometimes suggested that brass for making escape wheels should be extra hardened by hammering. In my own experience this is not necessary. It is only necessary that the material is hard enough to withstand deformation during the wheel's manufacture and the hard-rolled condition would be adequate for this. If the impact of locking has any effect it will be to work-harden the contact points. If the friction of unlocking is high enough to cause wear then the escapement could not function. Escape-wheel teeth will show signs of wear only if the jewels are incorrectly polished. It is especially important to ensure that the corners of chronometer locking stones and lever pallet stones are not finished to a sharp edge that can cause wear to the tip of the tooth by scraping.

As with steel, the addition of 3 per cent to 3.5 per cent lead will produce free-cutting brass, with swarf in the form of powder or small chips. However, this brass is too brittle for fine components and will offer lower resistance to deformation. It is particularly unsuitable for wheels with delicate teeth.

Binding Wire

Iron wire is needed in casemaking for holding components in position during soldering. It is useful also in a variety of ways when hardening steel. These are described as appropriate to the work in hand. For casework, wire of 0.3 mm diameter is required. For other work diameters of 0.5 mm and 1 mm will meet all requirements.

Always test new supplies of wire before use. Raise a length to red heat and plunge into water. Thin wire can be screwed into a ball for this purpose. The wire should remain quite soft after this treatment.

Shellac

Shellac is used for cementing jewel stones into position and for securing components in wax chucks. It can be melted into a thick, gummy liquid with very little heat so that the jewel can be carefully positioned before cooling when the shellac will become hard again.

Place a small chip of the shellac upon the joint of the jewel and the component to which it is to be cemented, and heat over the spirit lamp until the shellac melts. Slide the jewel in and out of its slot or hole to ensure that the melted shellac penetrates fully. When cool any excess of shellac can be removed with a brass scraper. During heating, the component and the shellac must be protected from the direct heat of the lamp. The 'blueing' plate can be used for this purpose.

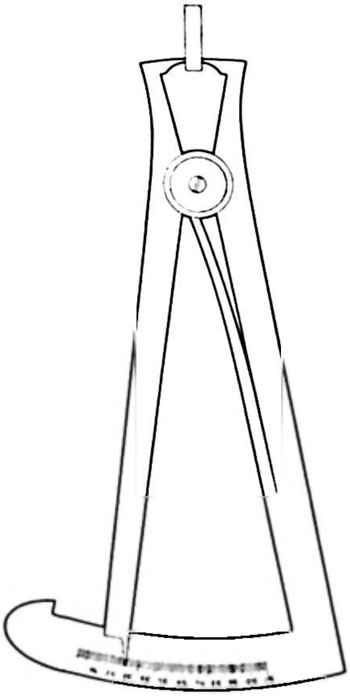
If it is required to remove all of the shellac from a component, as will be the case after using the wax chuck, the shellac can be dissolved in methylated spirits. Put a little spirit in a metal container and heat over the spirit lamp. The shellac will dissolve away leaving the component clean. If the spirit catches fire place the container on the bench and muffle the flame with a cover.

Good shellac is golden in colour and hard enough to resist chipping easily. Shellac which is brown in colour and chips easily under pressure from a sharp point will not properly secure the jewel. Test for security after cooling by reasonable pressure on the stone. It will not move if the shellac is correctly constituted.

Measuring Tools and Gauges

Micrometers

The ordinary, millimetre, hand micrometer and a good-quality vernier gauge will serve the general measuring requirements of the watchmaker. In selecting a micrometer choose one that measures to 0.01 mm and with square edges to the anvil and screw faces. The micrometer is ideally suited to measuring the diameter of work without removing it from the lathe. It offers a convenient means of checking that the work is parallel by sighting across the polished faces of the anvil and screw, and is an accurate means of measuring the diameters of a taper. It can also, simply and surely, check plates and bridges for uniformity of height and thickness; and it can just as easily measure very small pieces, when they are placed on the anvil with the micrometer vertical and the screw brought down to meet them.



Pivoted gauge with millimetre scale

Vernier Gauges

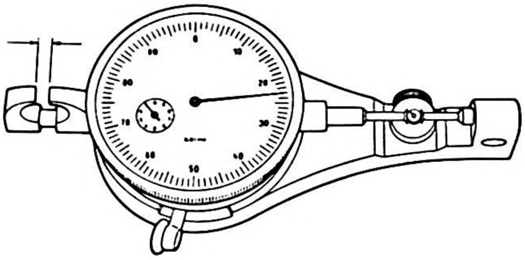
The sliding gauge with vernier scale measuring to 0.01 mm will measure inside and outside diameters, depths of recesses and lengths or arbors. Choose an instrument with a fine screw adjustment for the sliding limb. It is not really convenient to measure small components by sliding the limb with the thumb, as is necessary without the screw adjustment.

Douzième Gauges

The pivoted gauge, illustrated in Fig 17, will measure the thickness of curved surfaces. This is usually referred to as a *douzième* gauge and indicates twelfths of a French inch. A millimetre scale is more useful and the *douzième* scale can, if necessary, be erased and a millimetre scale substituted. Use the vernier gauge for this purpose and mark off first the whole centimetre and then subdivide it into millimetres. This tool is not intended to be a precise measuring instrument but with intelligent use can measure to within a few hundredths of a millimetre. When measuring the thickness of a curved surface, a case back for example, fasten the jaws on to the work and rock the tool to indicate the lowest possible reading on the scale.

Dial Gauges

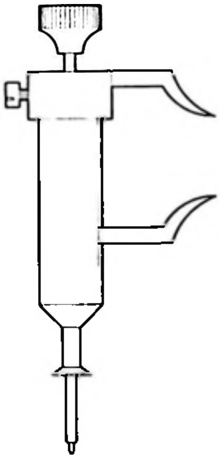
The dial micrometer, illustrated in Fig 18, is most convenient for measuring small, delicate pieces. Pinions, staffs and arbors, etc., can be held in the tweezers on the anvil while the measuring surface is released to meet them. The jaws will conveniently measure the thickness of detent springs and similar delicate pieces. The dial is calibrated in hundredths of a millimetre and one revolution of the centre hand equals one millimetre at the measuring points. The subsidiary dial indicates whole revolutions of the centre hand.



18 Dial gauge to measure hundredths of a millimetre

Comparator Gauges

In addition to the graduated measuring instruments, watchmakers will find many uses for comparator gauges, plug gauges and proportional gauges, etc. A useful comparator gauge for taking the height of a shoulder or sink is illustrated in Fig 19. The centre rod is a sliding fit in the brass body and can be used for taking the height. The upper jaws embrace the same distance as the length of pin extended. If the end of the rod is pointed it will enter a jewel hole without passing through, and the distance from the point to the flange will be the length from the end of the pivot to any required height.



19 Comparator depth gauge

Plug Gauges

Tapered and parallel plug gauges offer greater ease for measuring hole diameters, especially when boring in the lathe. Tapered gauges can be made and marked in convenient intervals. Measure the diameter with a micrometer after noting the mark closest to the hole to be measured.

Parallel gauges can be made as required and are especially useful when boring holes for pivot jewels with standard diameters. They can be made from blued-steel rod and require no further heat treatment. A convenient length is about 20 mm. Turn the length of rod to the full diameter of the jewel and reduce one end to two smaller diameters to help measure the progress of the boring. Thus for a jewel of 1.8 mm, turn the rod to 1.8 mm throughout its length. Reduce one end, for a length of 4 mm, to a diameter of 1.75 mm and further reduce the end 2 mm to a diameter of 1.7 mm. Turning the length of the rod to the diameter of the jewel simply allows a rapid method for selecting the correct gauge by measurement with a micrometer. In use the gauge is offered to the hole until it is large enough to admit the smallest diameter. From then the hole can be enlarged with greater caution until the second diameter enters freely. The hole will now be ready to receive the jewel broach for final enlargement to fit the jewel. This method of checking the diameter of a hole as it approaches size is particularly useful when the work cannot be removed from the lathe. The jewel broach can be used directly to gauge the progress of the boring.

Pivot Gauges

The principle of using fixed diameters to measure the progress of work can be used also for measuring pivot diameters. Accurate gauges can be purchased in the form of graduated jewel holes set in a convenient lightweight plate. The pivot is reduced until it will just enter the next hole larger to the required size and it will then be ready for final polishing.

Wheel Plate

A wheel plate is convenient for measuring the diameters of delicate wheels and especially escape wheels with uneven numbers of teeth. The recesses for receiving the wheels are graduated in diameter by 0.1 mm increments.

Pinion or Wire Gauges

A pinion gauge plate is useful for comparing pinion diameters, especially when they are of small diameter and have uneven numbers of leaves. When replacing a damaged pinion observe the number of the smallest hole that the pinion will enter and select a new one to fit the same hole. The usefulness of these plates is increased if the holes are marked in millimetres, and when the size of a pinion is known the reverse of the plate can be marked for future reference. The Swiss pinions supplied by material shops are numbered for size to suit the gauge plate and the selection of the correct size by comparison in the plate is simplified.

Pointing and Boring Machines

These machines were devised in American and Swiss factories in the nineteenth century to ensure the accuracy required of tools to make interchangeable components. The early machines used screw threads and graduated drums with vernier scales corrected for screw error by correcting cams. Later machines have glass scales with background illumination and translucent vernier scales.

The machines are used for optical measuring, pointing and boring. A microscope is usually at the centre of the machine for centring work. Flanking this are optical sights for measuring the distance the workpiece is moved relative to the centring microscope. The measurement is taken directly from millimetre scales and can be read to 0.001 mm by means of vernier scales.

Once the workpiece is correctly positioned the microscope can be replaced with a point to make a centre. If required the centre can be drilled by replacing the point with a drilling collet. The drilled hole can, if required, be enlarged with a boring tool to ensure complete accuracy of position. It is possible to make accurately two holes, separated by the required distance, to within 0.001 mm. The watchmaker does not need to work to such close limits, but any machine that can work closer than the required limit of accuracy will obviously simplify the work in hand.

In order to use the machine it is first necessary to make a large-scale drawing of the component required. This is most accurately done with a co-ordinate measuring machine to mark the cardinal points of the component which can then be linked by hand with a pencil to mark the outline. The drawing is made to a large scale and the dimensions to be transferred to the pointing machine are taken from the drawing.

Dimensions of the Components

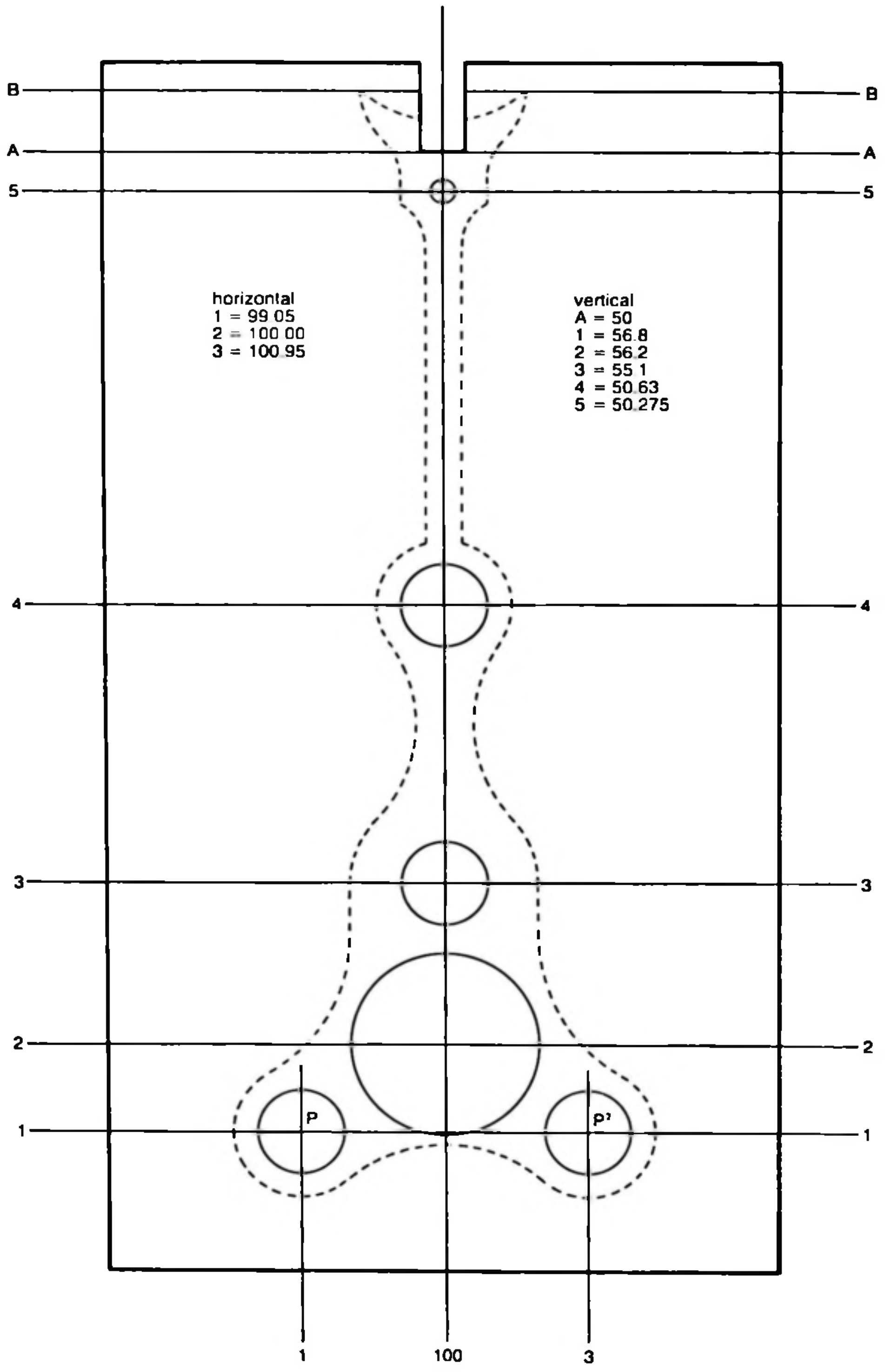
The drawing can be made to scale without the co-ordinate machine and dimensions taken from it with a good ruler. The lever of the watch illustrated in Plate V has several critical dimensions, and a large-scale drawing of the escapement is required to ensure accuracy. A scale of 100:1 would suit and an error of 0.2 mm in the measurement taken from the drawing would give a component error of 0.002 mm, which is too small to matter.

With the drawing completed measure the positions of the cardinal points along the horizontal and vertical axes. Dimension the positions relative to a chosen reference figure for each axis. In Fig 20 the chosen horizontal reference is 100 and the vertical reference is 50. These two lines pass through the bottom of the notch. All other positions are marked in terms of reference numbers. Pin P is to the left of 100 and so is positioned at 99.05 mm. Pin P^2 is to the right of 100 and so is positioned at 100.95 mm.

Setting the Machine

Prepare the steel for the pallets by stoning smooth. Cut the notch for the fork to a convenient depth. Set the pointing machine's horizontal and vertical axes to the reference figures and clamp the steel to the table. With the auxiliary screws and rotating table, set the centre of the notch on line A at the centre of the microscope with the edge of the notch parallel to the vertical axis.

Set the vertical and horizontal axes to co-ordinate 1. Replace the microscope with a point and mark position P. Move to horizontal 3 and mark P^2. Reset the horizontal axis to reference 100 and mark the remaining vertical co-ordinates. Finally, with the scribing point,


B
B
A
A
5
5
horizontal
1 = 99.05
2 = 100.00
3 = 100.95
vertical
A = 50
1 = 56.8
2 = 56.2
3 = 55.1
4 = 50.63
5 = 50.275
4
4
3
3
2
2
P
P'
1
1
1
100
3

20 Co-ordinate plan for pointing machine

scribe the line *B* on the steel as a guide to forming the horns of the lever.

Drill the holes to the required diameters as the points are recentred by following the co-ordinate sequence again. The component is now ready to cut out with the certainty that it is quite accurate.

Versatility

The machine is equally useful for marking out plates for wheel trains and planting escapement components. In each case make a large-scale drawing and take the measurements from the drawing. For uprighting wheels simply centre the lower hole in the microscope and point and drill the upper hole. If the hole needs to be enlarged replace the point with the boring tool fitted with a suitable cutter. The boring tool has provision for offsetting the cutter to enlarge the hole.

The machine is primarily intended for making jigs and tools for use in the mass production of watches. It has limited uses for the watchmaker but for making a complex component requiring critical accuracy of drilling it is invaluable and can save many hours of work.

Pointing with the Lathe

With only a little inconvenience a lathe equipped with a vertical slide with microscope and drilling quill can do the same work. Attach the workpiece to the mandrel plate with the headstock spindle locked. Take the vertical co-ordinates with the vertical slide and the horizontal co-ordinates with the cross slide. For drilling and boring use the longitudinal slide. To prevent accidental shifting of the drill, due to the vibration of the driving belt, always lower the quill to the drilling height so that the backlash in the vertical slide thread is taken up.

Adjust the slide gibs to minimum friction without free play so that small alterations can be made to the position of the drill without errors arising from flexure of the screw threads.

Optical Measuring

The comparator projector and epidiascope will project the silhouette of a component placed upon the measuring stage. The lenses are interchangeable for 10 ×, 20 × and 50 × magnification. The screen, with vernier for degrees at the edge, can be rotated. The movement of the vertical and horizontal axes of the measuring table is measured by screws with large thimbles graduated to 0.01 mm. With a drawing on tracing paper clipped to the screen a direct comparison of the accuracy of the component can be made.

The surface of the work can also be projected on to the screen so that the action of a working escapement is clearly seen. This is a simple and ready way of measuring the angles and dimensions of an escapement. The angle of draw and its efficacy, the balance amplitude and the action of the wheel and pinion depths can be studied closely with this optical measuring tool.

2

HAND TOOLS

General Bench Tools

Files

The files most commonly used in watchmaking are illustrated as appropriate to the work in hand. Handles are not usually required and the majority are made with long tangs which offer greater flexibility in use than could be achieved with a handle. Crossing files usually have a short tang and if the whole length of the cutting face is to be used a handle is helpful.

With the obvious exception of round and knife files all files need one or more safety edges. Half-round files usually have none and so cannot be used for fine curved filing up to a corner. The flat side must be ground off until both edges are sharp. Do this on a grinding wheel with the table brought up close to the wheel to support the file. Lay the file against the corner of the wheel with a gentle pressure and it will quickly find a level. After two or three slow strokes along its length the file can be cooled in water and examined. If more grinding is required the file will find its own angle against the wheel and the work will continue until the edges are sharp. When completed the file should be kept separately in a drawer kept especially for fine finishing files.

Double-faced crossing files can also be effectively used only on one face. The two faces have different curvatures and the flatter curve is usually the most useful. Grind away the edges of the unwanted side in the manner shown in Fig 237. Because watchmaking by traditional hand methods has virtually died out it is no longer worth while manufacturing these files and they are difficult to obtain. Coarser, double-curved files of smaller sizes are readily available and, ground in the same way as a crossing file, will quickly rough-cross out a wheel ready for the finishing file.

The flat, ridge-backed files are most frequently used in watchmaking and these should be bought with curved, tapered or parallel edges. Always dress the safety edges with an oilstone slip before using. When new the edges are rough from the cutting machine and quite unsuitable for use without dressing. These files are generally so useful that they can be obtained in many sizes and cuts for both coarse and very fine work. For getting into very sharp-angled corners the edges should be ground to razor sharpness. The smallest examples with very fine cuts are useful for bevelling the sharp edges of small, finished components.

Pillar files are flat faced with two safety edges and these also need dressing before use. Never presume that the safety edges are square to the cutting faces. Often they are not and this reduces the usefulness of the file when making square corners. They can be ground square on the face of the grindstone but this is tedious work and the watchmaker will do better to select the files carefully before purchasing.

Square files need a safety edge if they are to produce square corners. Quite often they have one when purchased but if not it is a simple matter to remove the cutting edge of the teeth on one face with an oilstone slip. The four faces are not always of uniform quality and they should be examined with a glass to select the least useful.

Knife files are used for slotting and are especially useful for making screw slots. They are best fitted into a folded metal handle to protect the fingers. For slotting very small screws these files can be reduced in thickness by stroking them across the face of the grindstone. Oil applied to the cutting edge will spread to the sides and reduce the tendency to jam in the slot. The depth to which these files will cut is very limited because the sides taper towards the cutting edge, but this adds to their usefulness for cutting screw slots which are the better for tapering to the bottom.

The triangular file is the least useful to the watchmaker and only a few of very fine cut need be purchased. Round and oval files are not often used but are indispensable when they are required. Keep a selection of sizes from about 150 mm overall length down to about 80 mm in medium and fine cuts. There is one kind of round file that is parallel throughout its length and has very coarse teeth. It is especially made for forming the grooves for the hinge tube of watch cases and small boxes.

Pliers

A pair of smooth-jawed, steel hand pliers will be useful for general work; a pair of brass-lined pliers will be needed for protecting components that need to be tightly gripped; and a small and a large pair of round-nosed pliers will satisfy most requirements and are especially useful for fashioning the ends of mainsprings.

Bow pliers are essential for springing a case bow when fitting or removing from the case. Their action is the reverse of ordinary pliers and the jaws open when the handles are squeezed.

Closing pliers are used for springing the bow more tightly to the pendant. One jaw is fitted with a brass lining, cut with semicircular grooves of reducing radius, while the other smooth, steel jaw fits into the hollow. The bow is placed in the appropriately sized groove and squeezed to reduce its free diameter. After refitting to the pendant with the bow pliers its diameter will revert to the original size but it will grip the bow more firmly.

Hand Vices and Sliding Tongs

A variety of hand vices will be required by the man who aspires to make every part of a watch from the smallest end piece to a *tourbillon* carriage. There are two basic types: those that are clamped with a screw and those that employ a metal loop to slide along the handles and hold the jaws closed. The latter are usually referred to as sliding tongs. Both are used for holding pieces firmly in the hand while filing or shaping. The clamping-screw variety are most suitable for large work, but as watchmakers do not usually make large parts clamping screws are not generally necessary. They are on the whole more suited to clockwork.

When purchasing tongs examine them to ensure the jaws meet at the front edge only. Jaws that touch over the whole area cannot grip the work at the front edge where working pressure will be applied. It is usually necessary to stone the jaws before using the tongs to remove the manufacturer's machining marks that would otherwise mark the work. Check that wide-jawed tongs are parallel along the whole width of the jaws and that the edges meet cleanly with no overlap. A pair with notches along the edge are useful for seeing that long, thin components, such as hands and return springs, are being reduced evenly in width throughout their length while they are being filed.

For shaping small, brass, wheel cocks; filing the spokes of wheels; and piercing *tourbillon* carriages, etc., a brass-faced pair of tongs is invaluable. Choose a light-weight pair with detachable steel jaws that can be replaced with brass cut to any convenient shape. Narrow-jawed tongs are used for holding smaller pieces of work and can be ground to any convenient shape to suit the work in hand.

Pin Vices

The versatile watchmaker will need several sizes of pin vices for holding wire and for use as temporary handles for broaches and files, etc. Choose a selection that will accommodate a diameter from 4 mm down to zero. Do not select double-ended pin vices nor those that have interchangeable collets for differently sized wires. Nothing is more distracting to the smooth flow of the work in hand than having to stop to prepare a tool for a minor operation. If the large end of a double-ended vice is used, the small end will impede the through passage of the wire. If a collet needs to be changed it may be that the correct size cannot readily be found. In either case the work must be put down while the tool is prepared and the distraction can result in loss of concentration and even lead to an accident.

All-steel, four-jawed pin vices, in the larger sizes, are most useful for holding broaches and small files when a handle is needed. For making small pins choose pin vices with long, thin, hollow handles. These will help to spin the tool in the fingers while filing.

Solid-handled tools will not allow the standard lengths of brass and blued-steel wire to pass through, and with a new length of wire this is inconvenient.

Make a small flat at a convenient place on all pin vices to allow the number of turns of the tool to be counted easily as, for example, when turning a barrel arbor to count the number of turns of mainspring available in the barrel.

Wire Cutters

For most requirements two pairs of smooth-faced end cutters will be sufficient. These can be obtained with square or angled faces and one pair of each should be chosen. The square-ended pair will be useful for the light cutting work required with gold or brass wire. The angled pair should be kept exclusively for cutting balance spring, collet and stud pins, where the angled extension will prove useful in making the cut close to the work. When new these cutters are carefully sharpened to a keen, true edge, which will soon deteriorate if the cutters are used on steel. Bevel-edged cutters are better for steel and the cutting edge, which is ground to a broader angle than that of the flat-faced cutters, will resist collapsing.

Broaches

Cutting and smoothing broaches are used for enlarging and polishing pivot holes. The cutting variety are used more often by the clockmaker, especially when opening worn plate holes to receive new bushes. Clock plates are usually too large to swing in the mandrel to bore the holes and the cutting broach is the only convenient alternative. The watchmaker will not generally need broaches exceeding 2 mm diameter. More likely sizes would be from about 1.5 mm down to 0.1 mm diameter for small, watch-pivot holes.

These small broaches are still available from some tool shops but can be quite easily made from steel wire if necessary. Select a piece of blued-steel wire of suitable thickness and draw it through the lamp flame until it is reduced to a dull-grey colour. It will now be soft enough to file without being completely annealed. Make a shallow groove in a piece of brass and, while held in a pin vice, place the wire in the groove and file to the required taper. Five equally spaced marks around the nose of the pin vice will be sufficient for a sight index to make the flats. Raise to red heat in an iron-wire sheath and harden in oil. The broach will now be delicate and great care will be needed to brighten one of the facets with an Arkansas slip so that it can be placed on a brass plate in the flame and brought to a pale-yellow colour. Finally, draw a stone slip along all the facets to produce a clean appearance. A cutting broach of any size can be sharpened by running an oilstone lengthways down the facets.

Smoothing broaches are essential for finishing pivot holes after broaching to size. Their surface should not be highly polished but prepared with a medium buff stick. This is used lengthways down the taper to help retain the oil without which they would tear the surface of the hole.

Tweezers

Good-quality, tempered-steel tweezers will suit most of the watchmaker's everyday requirements. They must be strong enough to hold large pieces safely and at the same time have a fine enough taper to pick up very small screws without difficulty. Choose a pair of which each limb is shaped with three facets to enable the tweezers to be rolled between the thumb and first two fingers when holding small objects. This is a knack which should be practised until the tweezers can be turned through 360° while holding a small component or a screw. Dexterity will be improved with each practice and the tweezers, when used for holding small objects for examination on all surfaces, will become a finer extension of the fingers.

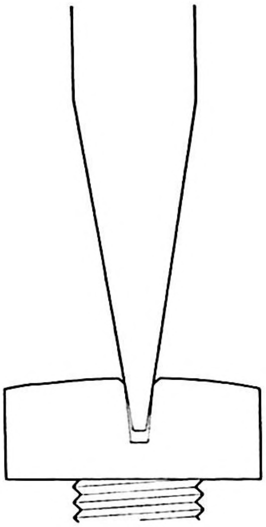
Brass tweezers do not seem to be used much by watchmakers, but they should be for they are more versatile than the steel variety. It is useful to have three pairs. One pair should be dressed to size for general bench use, such as assembly and examination of components either during assembly or manufacture. They will pick up irregularly shaped steel objects with much greater ease than steel tweezers. And because they are soft they will easily pick up components by their fine corners or edges and will not mark the work. This is especially useful for assembling a watch finished with blued-steel screws. A finer pair can be dressed to suit smaller work, such as picking up and fitting jewel stones which can be gripped quite firmly in brass tweezers. And a third and stout pair is useful for picking up heavy bridges and mainspring barrels without risk of marking their surfaces. They can also be used for holding pieces in the flame or, when pre-heated, for gripping rollers, etc., to soften shellac prior to moving a stone or pallet. Because brass tweezers are softer than the steel variety they soon show signs of rounding at the edges and tips, but it takes very little time to dress them with a file until the edges are square and ready again for safe use.

A pair of ivory tweezers are useful for handling polished gold and silver pieces and matt, gilt metal pieces. These are best made with the ivory limbs riveted to a spring steel handle. Before using them examine the inside surfaces for any dirt that could cause marks. They can be cleaned by gently scraping with a knife.

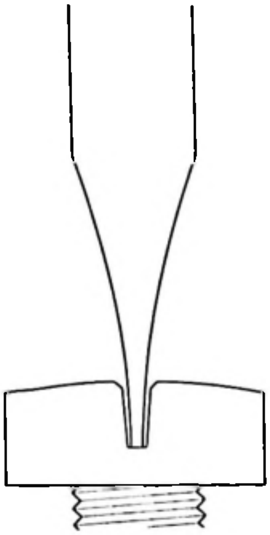
Screwdrivers

Simple lightweight screwdrivers with fluted brass handles, and hexagonal head buttons to prevent rolling on the bench, are the most convenient to use. The size of the blade will depend on the size of the screw head and a blade slightly narrower than the screw head should be used.

A carelessly used screwdriver can cause marks and scratches on the watch plates, and badly sharpened blades can damage the screw heads. The blade must be pressed firmly down into the screw-head



21 Correctly shaped screwdriver blade



22 Incorrectly shaped screwdriver blade

slot before the screwdriver is rotated, and if increase in the turning pressure is necessary the downward pressure must be proportionally increased. This may seem so obviously necessary as to be hardly worth mentioning, but as one sees so many marked screws the advice can do no harm.

The fit of the blade into the slot is important if the screwdriver is to be used deftly and with confidence. A correctly shaped blade fitting into a good slot is shown in Fig 21. Note that the flat edge of the blade does not reach the bottom of the slot and so cannot skid out sideways and the sides cannot mark the visible edge of the slot. Shaped and fitted in this way the screwdriver is securely locked by downward pressure into the slot and cannot cause an accident unless the turning pressure is excessive.

At one time screw slots were always bevelled at the edges to prevent marking but nowadays, probably in the interest of economy, the practice is almost discontinued. When making new screws the watchmaker can include this necessary refinement merely by the stroke of a file and the screws will retain their new appearance no matter how many times they are turned. It has been suggested that a blade sharpened in the manner of that illustrated in Fig 22 will prevent damage because the pressures are applied to the bottom of the slot. However, such a blade would seem more likely to cause an accident, either by breaking at its thinnest part or skidding sideways, because it is not locked by friction into the slot. It should be noted that screws must have freedom to turn in the thread, for this allows them to tilt sideways to an increasing angle as the thread is withdrawn. If the blade is sharpened, as shown in Fig 21, the tilting will be prevented, but a blade that rests on the bottom of the slot will increase it.

Screwdrivers are so cheap to buy and last for so long that they are hardly worth re-blading. In an emergency a blade can be made from carbon steel heated to a glowing red and dropped endways into hardening oil. Clean afterwards with a buff stick and temper on a brass plate to a medium-yellow colour. File the top approximately to shape before hardening and after hardening finish on an oilstone. Do not scrub the blade to and fro on the stone but set it carefully at the correct angle at one end of the stone and run it the whole length and back again without moving the angle of the wrist. In this way both sides will be perfectly flat and leave a parallel blade that will resist wear and prevent tilting in the screw slot.

Hammers

In addition to the conventional, small, forged or cast steel hammer, a fibre or leather-faced hammer will be needed for 'truing' work in the mandrel. Excellent hammers are available in the tool shops with replaceable fibre and bronze faces for which many uses can be found in the workshop.

A planishing hammer with a slightly convex face will be needed for hand-flattening metal, as is sometimes required for special purposes. And an anvil of about 60 lbs weight with a smooth table and beak is also invaluable on occasions.

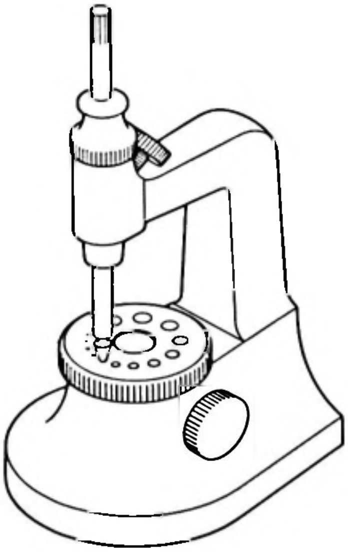
Saws

A small hack-saw will be needed for cutting off small pieces of material from sheet or rod. A jeweller's piercing saw is most convenient for cutting out the spaces of wheels and carriages, etc., and for cutting around the edges of very small components. The pitch of the teeth of the ribbon blades can be chosen to suit the thickness of the work to be cut. Fit the blades under tension so that they cut as the handle is pulled. If fitted to cut when the handle is pushed, the blades will slacken and break.

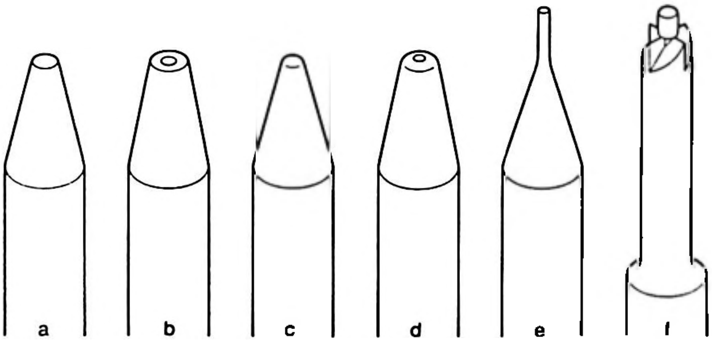
Staking Tool

A staking tool is essential for holding a punch vertical while riveting or broaching square holes. Modern tools, such as the one illustrated in Fig 23, should be accurately machined so that the punch is held quite vertically to the staking plate below. The plate can be rotated to bring the appropriate hole beneath the punch and locked in position by a screw. Some tools also have an eccentric carrier for the punch to enable it to be centred independently of the plate.

The principal punches supplied with the staking tool are for spreading, Fig **24**, *d*, and riveting, Fig **24**, *b*. These are supplied in pairs with the same-sized bore. The number of punches supplied will depend on the cost of the tool, but it is a sound investment to purchase an outfit with a complete set of punches for both spreading and riveting. For general work these will extend from 0.1 mm bore to 2.5 mm bore.

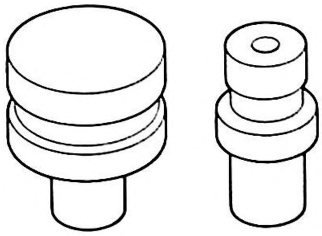


23 Staking tool



24 Staking tool punches

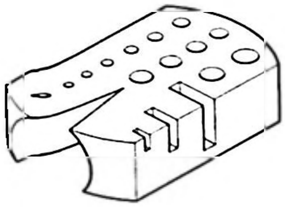
Some of the punches will rarely be used, but if not available when needed will have to be made. The same is true of the separate stakes, illustrated in Fig 25, and many different sizes will be needed from time to time. Some tools have an extra base to enable the punches to be inverted and used as stakes. This system can be useful at times but is never so convenient as the conventional small stakes. A range of a dozen stakes pierced from 0.5 mm diameter to 3 mm diameter will cover most requirements. Very often a plain unpierced stake is required and of these a dozen assorted sizes from 1 mm diameter up to 6 mm diameter will cover most needs.



25 Stakes and anvils for the staking tool

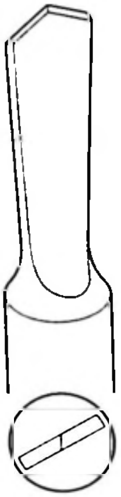
Some staking sets contain sets of plain punches, *a*; domed punches, *c*; pin punches, *e*; and various cutters and sinkers, see

Fig 24. The punches are always useful but the cutters do not perform very well in the staking tool. The cutter has a guide pin to prevent it wandering and it is extremely unlikely to fit the required diameter of the plate hole. Sinks are best made in the lathe. When the work cannot be held in the lathe the guide hole should be drilled to the size of the cutter guide pin and, on completion of the sink, the hole opened to the required size. The guide pin can be pulled out of the cutter and reduced if a smaller hole size is required.


26 Staking block

Some tools are designed to serve both as staking tools and jewelling tools, but as it is not usually convenient to change from one use to another; separate tools are always better. It is important to check that all punches are straight and that the faces of both punches and stakes are square. Check also that the punch is held square to the staking plate of the tool. Tools which are out of square can cause much aggravation if they are not discovered before use.

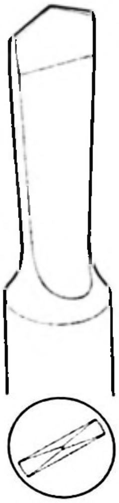
In addition to the staking tool, small staking blocks are very useful for a variety of purposes. A deep one with slots and a 'V' notch, illustrated in Fig 26, will fulfil most requirements. And as well as helping with a variety of initial assembly work they can also be used as a flat bed to check the flatness of small objects such as ratchet wheels and repeater racks.


27 Flat-blade drill

The working surfaces of stakes and punches must be maintained in good condition to avoid bruising the faces of the components being assembled. The most frequently used holes in the stake will eventually become worn at the edge. A small staking block can be replaced but a new plate for the staking tool may not be available. The plates are case-hardened and can be ground flat and re-hardened. Industrial toolmakers are especially equipped to do this work.

Drills and Drilling

The drills most readily available from tool shops are the flat, tapered drills of the type illustrated in Fig 27. These are quite satisfactory for the many different drilling operations undertaken in watchmaking. They are available in graduated sizes from 0.1 mm to 2 mm, rising in tenths of a millimetre. The shanks are made in three standard sizes of 1 mm, 1.5 mm and 2 mm diameter and so can be used conveniently in the lathe collets. The flat section allows greater simplicity in bringing the cutting faces to a symmetrical form when sharpening by eye. In Fig 27 it can be seen that within the circle the drill will cut, the cutting faces are chords of the circle and consequently become increasingly inefficient as the centre is reached. However, cutting action can be improved by dressing the edges in the manner illustrated in Fig 28. The pressure required to maintain the cutting action is much reduced by this small modification and the cutting speed will be increased even though the face is no longer vertical to the work.

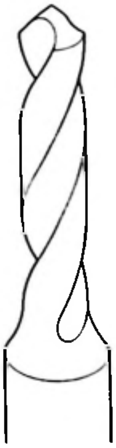

28 Reducing the centre width

To sharpen the drill hold it in a pin vice and then make a single steady stroke from the bottom to the top of a fine-grained oilstone. Now turn the drill and repeat the stroke for the other edge. Examine the drill and if any wear remains repeat the process until both edges are clean and sharp. Do not scrub the drill on the stone for this will form burrs on the cutting edge. Do not be tempted to remove all wear marks from one edge before starting on the other. Examine the drill from both sides after sharpening to ensure the symmetry of the cutting faces, and check the quality of the relief angles by slowly rotating the drill in the fingers while observing the tip. Finally, lay the blade flat on the stone as a guide to its level, before raising the shank so that only the point is in contact with the stone. Make one stroke to the end of the stone and back again to reduce the thickness of the centre. Turn the drill over and repeat the action. If the sharpening has been carefully done all the angles will be equal and the tip will be truly at the centre. The drill will cut a hole to the correct diameter and it will be parallel. If the tip is not at the centre the hole will be oversized, and if the angles are not equal the hole will be tapered with the large end at the exit. It should be remembered that after each sharpening, the drill will become a little smaller in diameter because of its tapered blade.

Cutting Speeds

Sharpened as described above the flat drill will cut quickly and with very little pressure. As with all cutting tools, cutting speed is important. Brass can be cut faster than steel and as the diameter of the drill increases the speed must decrease. As the speed is decreased so the pressure can be increased. Thus the speed at which the drill advances will remain much the same both for large and small drills even though the spindle speed varies with the size of the drill. The action of the cutting edges is resisted by the surface of the metal. This is overcome by applying pressure to the drill to force the edges beneath the surface of the metal. The rotation lifts the surface to allow the drill to advance always at the same depth to produce a continuous cutting action. If the pressure is too great the metal cannot be removed fast enough and the drill will jam under the cut and break. If the speed is increased to balance the pressure the drill will wear and bind in the hole. Thus the action is a continuous balance between cutting speed and pressure. Speed is the guiding factor for there is a maximum speed at which the drill will cut the material.

When the speed is correct the pressure can be adjusted by experience to produce a continuous flow of swarf while the blade of the drill remains free in the hole. As a guide to the beginner a flat drill of 0.3 mm will cut brass freely and without heating at 500 rpm and steel at 300 rpm, with the pressure applied to produce a continuous swarf from brass and fine chips from steel. A drill of 1 mm diameter will cut better at 300 rpm for brass and 200 rpm for steel, but the pressure would need to be increased to produce the same volume of swarf per unit of cutting width and consequently the same speed of advancement. Most beginners use excessively high cutting speeds so that the drill soon becomes blunt and refuses to cut. Careful preparation of the drill and thoughtful application of the cutting action will ensure success.



29 Fluted twist drill

Twist Drills

Fluted twist drills of the type illustrated in Fig 29 are becoming increasingly popular for small work. They can be obtained in both carbon steel and tungsten high-speed steel. They need less pressure than flat drills because the cutting face is angled to draw the edge into the metal. When drilling brass care must be taken to prevent the drill drawing too far into the metal and breaking off.

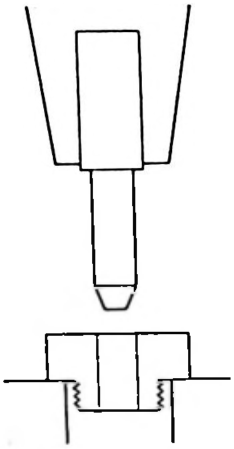
The drill is sharpened in the same way as the flat drill, but the relief angle to the cutting face must be kept shallow to prevent a broad tip and acute cutting edges that will easily chip. It should be noted that high-speed steel chips more easily than carbon steel but has better resistance to wear. The tip cannot be reduced as it can be with the flat drill and so twist drills are unsuitable for drilling hard steel. They are convenient for drilling deep holes, especially in steel, because the twisted flute will direct the swarf out of the hole and prevent the drill jamming.

Lubrication

It is not necessary to lubricate drills when drilling shallow holes. However, if the depth of the hole exceeds twice the diameter of the drill it can be lubricated merely by moistening with saliva applied with the tip of the finger. Although a lubricant will reduce wear on the drill corners, it will also bind the swarf and prevent it leaving the hole. The drill should, therefore, be repeatedly withdrawn from the hole and the swarf removed by wiping with the fingers. Re-moisten before continuing with the drilling.

Holes of Exact Size

The hole made by a drill will be larger in diameter than the measured diameter of the drill. If the drill is correctly sharpened the difference will be only one or two hundredths of a millimetre and of no importance to the general run of work. If a hole of an exact size is required it must be made with a smaller drill and opened to the correct size by other means. Engineers use reamers for this purpose but these are not made small enough for watchwork.

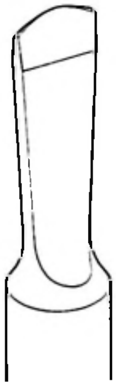


30 Opening a deep, parallel hole

Deeper holes that need to be parallel and to a predetermined size can be opened after drilling by forcing a smooth broach through the hole. Turn the broach in steel to about one and a half times the length of the hole to be opened. Make a small taper at one end to assist its true passage through the hole. Harden the broach in oil and temper to a medium-straw colour. Polish the surface quite smooth and to the required size. Lubricate the hole and broach with oil and fit up in the staking tool, as illustrated in Fig 30 which shows a rack bearing requiring a smooth, parallel hole. Drive the broach through the hole until the full length of the taper appears at the lower end. The hole will set to the size of the broach which can then be removed by light blows with a brass hammer on the tapered end. The resultant hole will be quite smooth and parallel throughout its length. When the component is ready for final hardening plug the hole with brass wire to prevent oxidation from the heat. A deep hole can be drilled more certainly without a taper if a pilot hole is drilled first. For example if a 1 mm hole is required drill through first with a 0.8 mm drill and follow with the 1 mm drill.

Small components needing concentric holes can be most conveniently drilled in the lathe. A drilling tailstock is a great help but not absolutely necessary. The drill can be held in a pin vice and aligned by eye for shallow holes or maintained in alignment by the tailstock for deeper holes. Make a chamfer with a sharp graver to locate the drill. The chamfer must be deep enough to locate the drill by the shoulder of the cutting edge or there is a danger that it will run off and produce an eccentric hole.

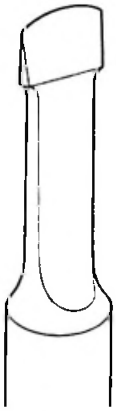
A 'V' pad for the tailstock is a most useful accessory for accurately drilling holes in round rods. To do this the drill should be held in the headstock and the pad rotated to the best position for observing the truth of drilling. If the drill starts to one or other side of the centre line the rod can easily be turned to the correct position.



31 Pivoting drill

Drilling Tempered Steel

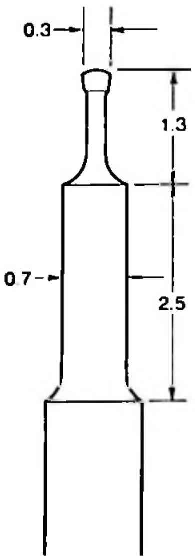
Arbors and pinions, etc., that need re-pivoting are also drilled in the lathe. The conveniently sharpened flat drill is not suitable for this work. The arbor will be hard and although its temper will be lowered to aid drilling it will still be hard enough to resist the tip of a conventional drill. Sharpen the drill to the form illustrated in Fig **31** so that the delicate tip becomes a broader edge better able to cut the metal at the centre. Leaving the flanks of the cutting edges at their original angles will help to prevent wandering, as usually happens with a round-ended drill. Draw the temper of the arbor to a pale-blue colour. This will leave it soft enough to drill but still sufficiently hard to resist deformation when finishing the fitted pivot.



32 Drill for hard steel

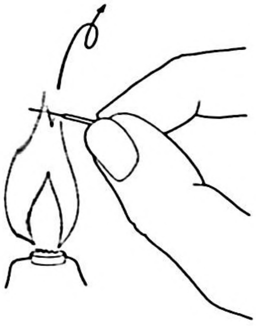
For drilling harder steel the tip of the drill is better shaped as that illustrated in Fig 32. The exact shape is not important but it should not have a point, as would be used with softer metals. The point would soon become blunt with the extra cutting pressure required to maintain cutting action. Note also the increased taper of the blade to reduce friction at the shoulder. If this is excessive, although freedom will be greater, the drill will also be rapidly reduced in diameter with any sharpening that may be necessary as the hole progresses.

Keep the blade short to increase its rigidity. A blade of about 1.3 mm length will be sufficient to drill a hole 1 mm in depth, which is deep enough for a pivot of up to 0.2 mm diameter. The hole can be shallower for smaller pivots and a good rule is to drill to a depth one and a half times the length that the pivot will be when finished. Thus the drill can be quite rigid although small in diameter. The drill illustrated in Fig 33 is turned in the lathe from a steel rod and the dimensions shown may serve as a guide to shape and rigidity. The thin shank will cool quickly during hardening to prevent the temper being drawn from the tip. The blade must be brought to a bright-red heat and cooled instantly to reach the desired degree of hardness for drilling. There will not be sufficient time to plunge the drill into cooling liquid before the heat has dissipated but if



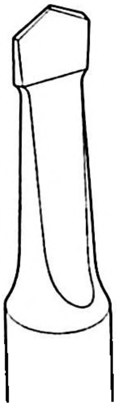
33 Stiff drill for small pivots

withdrawn from the frame quickly enough it will harden in the air.



34 Hardening fine drills

Hold the drill shank in the flame by finger and thumb, as shown in Fig 34. Draw it through the flame until the blade glows uniformly red to the tip. Withdraw it from the flame as quickly as possible and at the same time spin the drill by rolling the thumb over the finger. Withdrawn in this way the drill will make three or four revolutions in the fraction of a second it takes to cool, and will be prevented from warping through too rapid cooling on one side. The drill will need very little tempering. It will be sufficient to brighten the shank and hold the end in the flame until a pale-straw colour reaches the foot of the blade. At this stage cool the drill by immersing it. It is not necessary for the colour to reach the tip of the drill, which will receive enough heat from the shank to alleviate extreme brittleness.



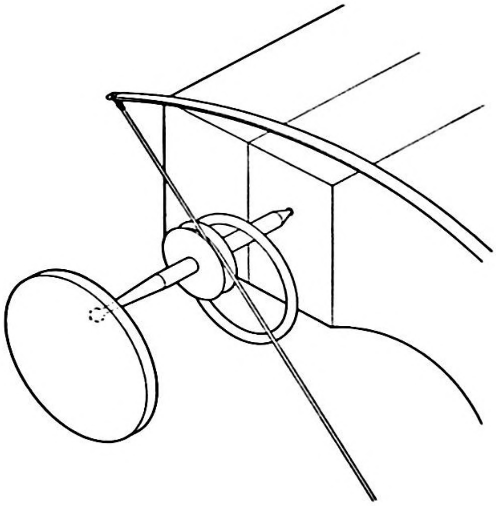
35 Finishing drill for pivots

If, during drilling, it is necessary to sharpen the drill the hole will not be parallel because the drill will have been reduced in diameter by reason of its tapered blade. Wear at the cutting shoulder will also cause a change in the diameter of the hole even though the drill may continue to advance. It may be thought that any taper in the hole could be compensated by tapering the pivot pin to fit. The difficulty is that the condition of the hole cannot be accurately assessed and the fit of the pin cannot be assured. It cannot be secured by making it a tighter fit, and driving it hard home for this might split the arbor. It has sometimes been suggested that oilstone dust will 'key' the pivot into the hole. This will result in a botched job and will certainly be an admission of failure to do the work in a professional manner. The simple method is to make the hole parallel and the pivot can then be fitted perfectly. To do this a further drill is required. Turn and file it to the shape illustrated in Fig 35 and harden as already described. The diameter of the parallel portion should be turned to a size that will just enter the mouth of the newly drilled hole.

Drilling Methods

The most accurate drilling is done by rotating the work. When accuracy is required this method should be used. The usual arrangement for holding the work is shown in Fig 542. When it is not necessary for a hole to be precisely located, a more convenient method of rotating the drill can be used. Before the introduction of small machine tools drilling was done by hand methods. Fitted with a ferrule, the drill was turned with a bow and held steady, as shown in Fig 36. Viewed from above the uprightness to the work is maintained by eye. At the same time the horizontal uprightness is observed by making sure that the loose ring on the drill is free from touching at either end. Watchmakers' vices still have the chamfers for locating the drill and this method is still practised by jewellers.

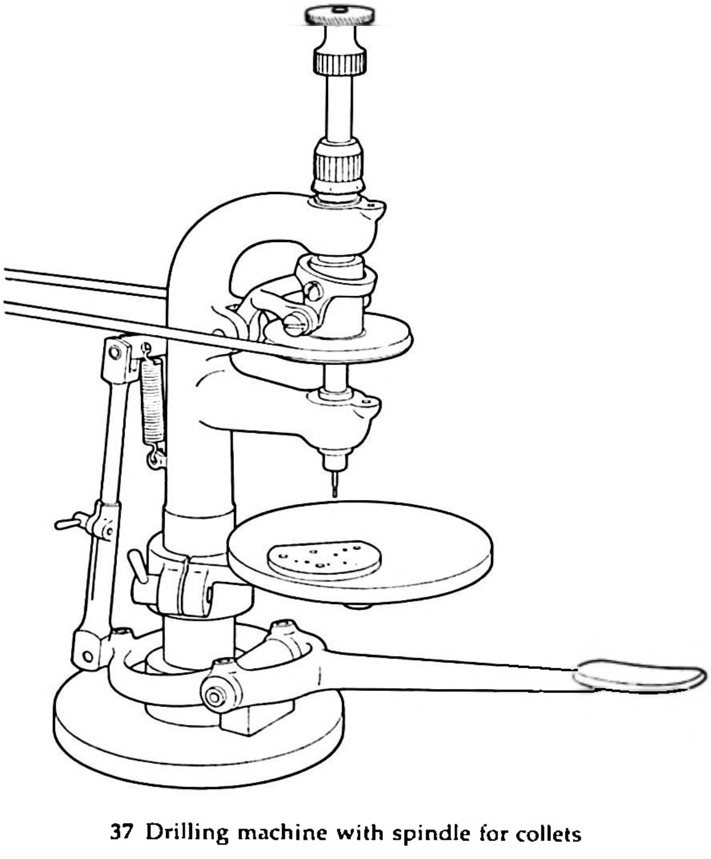
The drilling machine is more suited to watchmaking now that the good-quality drills are available in graduated sizes. The machine should have a light and sensitive action and be driven by a variable speed motor with foot control. This will leave both hands free to steady the work and locate the drill in the chamfer before switching on the motor. Bring the drill down just to enter the chamfer. Start the motor and, with the work held lightly with one hand, bring the



36 Drilling with the bow

drill gently down into contact with it. This will allow the drill to centre accurately in the chamfer. Once the hole is started hold the work more firmly.

A drilling quill that will receive the collets of the lathe is most convenient. Many thousands of small machines are used in watch factories and these are often available in tool shops, see Fig 37.



37 Drilling machine with spindle for collets

Make sure that any slack linkage in the quill operating lever is reduced to a minimum. An excess will allow the drill to fall through the hole once the point has pierced. Small drills will certainly break if this happens and large drills will leave a ragged burr at the exit. Always use a loose brass plate to protect the drilling machine table. If the drill catches an old drilling on the table surface it may break or bow in the hole and raise a burr at one side.

Screws and Threading

Screws with metric diameters and standard thread pitches are used for the majority of modern watchwork. A steel cutting die is used to form the thread of the screw and a steel tap of equal pitch is used to form the thread of the hole. It is usual for the die to produce a slightly smaller diameter thread than the diameter of the equivalent tap. This ensures freedom for the screw in the thread of the hole.

Sets of taps and dies can be bought from tool shops and are usually supplied with a table of correct diameters for screw threads before threading, and diameters of holes before tapping. For threading holes the suggested diameter of the hole is one that is larger than the thread root diameter of the tap. For cutting screw threads the suggested diameter of the shaft is one that is smaller than the thread root diameter of the die. The difference is very small and amounts to only one or two hundredths of a millimeter, depending upon the size of the thread. This difference in diameter is necessary to relieve the extra pressure at the root caused by the burr thrown up during the cutting action. This burr will be forced into the root of the cutter and cause it to jam on the work. If this happens there is a risk of breaking the shaft of the screw in the die or breaking the tap in the work. With the correct size hole or shaft the burr will form on the peaks of the thread of the work and form part of the full diameter.

Taps and dies are tempered during manufacture to prevent chipping of the thread during use. For this reason they should never be used on steel that is not fully annealed. To do so would certainly damage the cutting edge and prevent the formation of a full thread. It is essential to use a lubricant when forming threads to prevent the metal binding to the cutter and producing a rough surface to the thread.

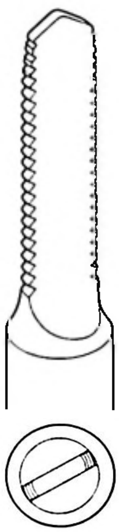
Tap Holders

When using the tap a holder will be necessary to obtain enough turning purchase. For taps of 0.7 mm diameter and larger a small pin vice will be suitable and the four-jawed, hollow steel type is ideal because of its light weight and small-diameter handle. Smaller diameters need a still lighter holder and this can be made by cutting off the handle of the smallest steel holder and substituting one of wood. Further weight reduction can be achieved by reducing the thickness of the tightening ferrule and the neck of the tool. Lightweight holders are important when using very small taps for they are easily broken if the holder is too heavy.

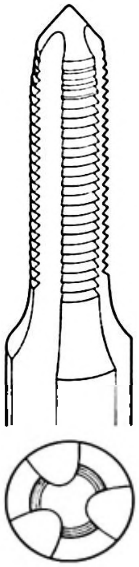
Threading a Hole

When starting a thread press the tap lightly into the hole and turn it just sufficiently to bite into the edge of the hole. Now turn the work and ensure that the tap is vertical. If it is not release the pressure on the cutting edge and re-start the thread. If the piece to be threaded is lighter than the tap holder then the truth of the tap can be verified by turning the work with the tap holder. If it is too heavy to examine in this way then the work must be turned while the tap supports the weight of the tap holder. If the tap is very small then the merit of lightweight holders will be appreciated. When satisfied that the tap is started quite vertically it can be advanced for a further whole turn to establish the thread.

Careful thought must be given to the form of the cutting edge when advancing the tap further to complete the thread. There are two basic forms arising from the cutting clearance of the tap. The early form, shown in Fig 38, has two flats and the cutting face is a chord of the diameter. The later form, shown in Fig 39, has three flutes and the cutting face is radial. The fluted tap will cut more easily than the flat variety. For this reason they can be advanced more quickly and need less withdrawal to clear the swarf. The flat taps have a compressing action on the metal as it is cut and so require more effort to turn. The swarf cannot curl up into the centre of the tap and as a result is not so easily sheared. For this reason the tap should be advanced by quarter turns only and reversed after each advancement until the swarf is sheared. Failure to do this will result in the tap locking in the hole and able to turn in either direction only as far as the compressed swarf. This is especially likely to happen when tapping steel where the depth of the hole exceeds twice the diameter of the tap. The fluted tap is better suited to shearing the swarf and can be advanced with less effort. Because



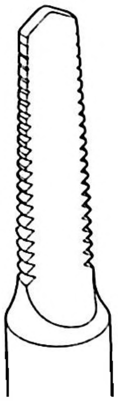
38 Flat-blade tap



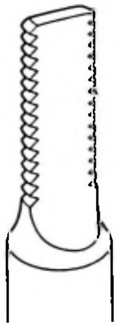
39 Fluted tap

it has three cutting faces it does not need to be reversed so far after each advancement and will not lock in the hole.

To help the tap get started in the hole the cutting faces are gradually reduced from the full thread down to the root diameter for the first few turns of the thread. When threading deep, blind holes this reduction should be in the form of a long taper to relieve the cutting pressure from the starting threads of the tap. Shape the tap as shown in Fig **40**. Note the slight relief to the back of the cutting edge extending to the whole length of the thread. This should be no more than is necesary to be quite sure that the cutting face has the greater radius. Without the relief the tap will bind in a deep hole but if the angle is excessive the tap will be unable to clear the swarf during withdrawal. After the hole is threaded to the required depth with the taper tap it can be opened to a full thread diameter with a normal tap. If a full thread to the bottom of the hole is needed then the second tap can be followed by a plug tap, shaped as in Fig **41**.



40 Starting tap for blind holes

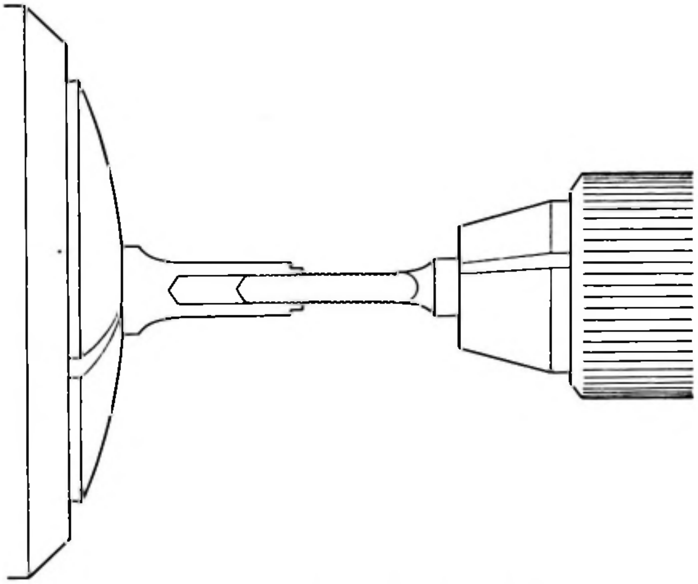


41 Finishing tap for blind holes

When tapping blind holes the diameter of the drilling is critical. Obviously if the hole is made too large then a full thread cannot be formed. If it is too small the tap will not turn and attempts to persuade it to do so will probably cause it to break. To check the diameter of the hole make a drilling to the required depth in a piece of scrap metal and measure the diameter of the hole with a plug gauge turned to the required diameter. The gauge should enter the hole freely and without side play. It is usual for a drill to make a larger hole than its indicated size and it is often necessary first to make suitable drills when precise hole diameters are required.

Threading Holes in the Lathe

When tapping small pieces such as rack bearings, threaded bushes, *tourbillon* carriage pillars, etc., the work can be done in the lathe. Fig 42 illustrates a carriage pillar of steel in the collet of the lathe. The weight of the tap holder is carried by the hollow tailstock which also holds the tap vertical to the pillar faces. Advance the tap by rotating the pin vice and withdraw to shear the burr by rotating the headstock with the belt removed. Advance the taper tap by no more



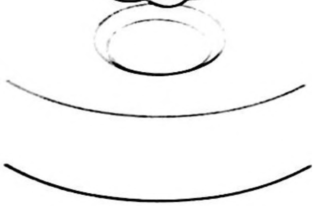
42 Threading blind holes in the lathe

than one-eighth of a turn and for each advancement reverse it a quarter turn. By turning the headstock for the withdrawal and returning to the cutting point the delicate grip on the tap holder can be constantly maintained and sensitivity to the cutting action retained. After each full turn withdraw the tap completely and remove the swarf with a brush. With the tailstock carefully positioned on the bed of the lathe before starting, the tap can be withdrawn sufficiently for brushing without disturbing the set-up. After each brushing relubricate with thin oil. When the hole is threaded to its full depth, change the tap for one of full diameter and repeat the process to achieve a full diameter thread.

The tapping of a small, deep, blind hole in steel is the most difficult threading that the watchmaker will need to accomplish. With care and patience the required sensitivity is soon developed and success assured. Clearly the work cannot be hurried if a mishap is to be avoided but a practised hand will be able to thread a hole, for example, of 0.5 mm diameter and 2 mm depth in a few minutes.

Chamfers

When tapping holes in a watch plate, or other flat surface, sink the hole to be tapped on both sides of the plate with a round cutter to prevent the tap forming a burr at the edge of the hole, as illustrated in Fig 43. This is especially necessary with flat taps which compress the metal as the thread is advanced.

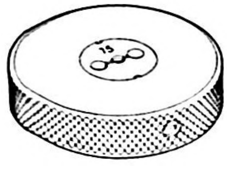


43 Chamfer holes before threading

Threading a Screw

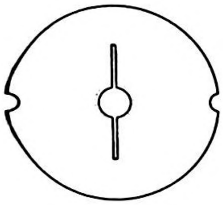
Dies for small screw threading are usually in the form of steel discs with a centre hole for the cutting thread flanked by clearance holes to form the cutting edges and clear the swarf. Useful sizes for watchmaking are from 0.3 mm up to about 1.4 mm diameter thread.

They can usually be most conveniently held in a circular holder with a knurled edge, as illustrated in Fig **44**. These holders have a peg to prevent the die turning and a screw to lock it into the recess.

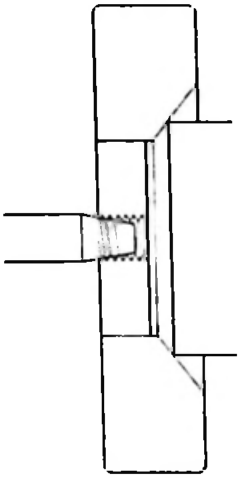

44 Holder for small dies

The diameter of the thread is stamped on the lead face of the dies and the back face is hollowed out to reduce the number of threads and thereby reduce friction. The die must always be started with the lead face which has the relieved threads to allow the work to enter.

It is usual to turn the shaft to be threaded in the lathe, in which case the thread is simply made by placing the die on to the end of the shaft and rotating the headstock. It is important that the shaft is turned to the correct diameter, especially for the smaller dies. These do not have the clearance holes to form the cutting edges but have instead a slot cut across the diameter of the thread hole. In Fig **45** it can be seen that these edges are chords of the cutting hole and consequently will not cut so freely as the edges of the larger dies. They will in fact form the thread by compressing the metal into the root of the die thread.

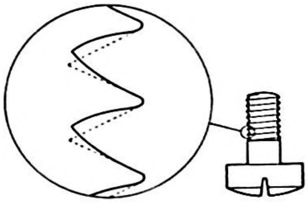

45 Chordal cutting edge of small die

If the dies are purchased as a set the correct diameters of the shafts to be threaded will be supplied with them. If the diameters are not known the following method will help to obtain them. For a 0.5 mm diameter thread, turn the shaft exactly to this diameter and keep it longer than the final required length. Reduce the surplus length to a taper so that the end will just fit the die, as illustrated in Fig **46**. Bring up the tailstock runner to hold the die square to the shaft and with a light pressure on the end of the runner turn the headstock to start the thread. For a small thread the friction between the face of the runner and the back of the die holder will be sufficient to prevent the die turning. Continue turning the spindle until the die jams on the shaft. Now remove the die and examine the part-formed thread on the taper. If no full threads are formed the die must be screwed further along the taper until a full-diameter thread is formed. When a full thread is obtained measure its diameter with the micrometer and reduce the shaft to the measurement obtained plus a further reduction of 0.02 mm to give clearance to the root of the die. Thus if the measured diameter of the full thread is 0.48 mm the diameter of the shaft will be reduced to 0.46 mm before threading. This diameter is important if a good, full thread is to be formed without risk of breaking the work in the die. In reducing the shaft the tip of the trial full thread will also be reduced but this will form fully on the useful part of the shaft. The taper will be cut away when the thread is completed.


46 Finding the thread diameter by trial

With small threads the die must be withdrawn after each advancement to clear any swarf and allow the lubricant to reach the cutting edges which quickly become dry under pressure. The larger dies with clearance holes can be advanced at a steady speed. A drop of oil placed on the shaft will keep the cutting edges supplied with fresh oil as they advance. Keep the tailstock runner against the back of the die for the whole length of the thread to ensure that the die remains square to the shaft. If the die is not maintained square, the lead of the thread will change at diametrically opposed points and the work will be ruined. To check the truth of the thread withdraw the die for a half turn and spin the work and die together. If the thread is true the die will rotate without wobbling on the thread. Threads can also be checked quite closely by watching their advancement as the shaft is rotated. Any hesitation or acceleration in the apparent movement of the thread along the shaft indicates a poor thread.

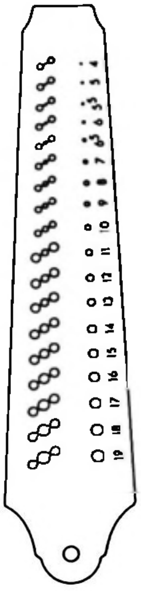
When the starting threads of a die have become worn they will resist the advancement of the die and produce a deformed thread, as illustrated in Fig 47. This can be prevented by increasing the pressure on the back of the die to help its advancement. Such dies are better suited to threading shafts that cannot be held in the lathe and especially when the die is rotated in the hand. When used in the hand a new die must be closely watched to be sure it starts squarely. If at all out of square it will cut into one side of the work which will then be ruined. A die that has lost its keen edge will not cut so fiercely and is better suited to self-alignment with the work.



47 Deformed thread from worn die

Screw Plates

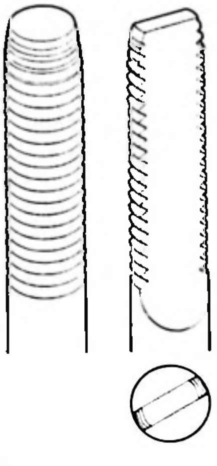
The screw plate is not so much used now that standard sized taps and dies are available. For small threads up to 0.6 mm diameter the screw plate offers no advantage, but for the larger diameters they are often useful because of their finer thread pitch. A plate is illustrated in Fig 48 and it can be seen that the thread holes are numbered for association with the appropriate tap. The threads are duplicated and one set have clearance holes to help in the cutting. These duplicate holes are used for final forming of the cut thread. The plates are supplied with taps when purchased but it is better to make taps from the plate as required.



48 Screw thread plate

To make the tap turn the shaft to be threaded with a tapered end as described earlier. Start the plate and measure the first full thread as a guide to the correct diameter. The shaft can now be reduced ready for threading, but the extra reduction will need to be increased to allow for the action of the plate which will not cut so freely as a modern die. The reduction can be determined by experience with the plate and the material to be threaded. In forming the thread the plate will partly cut and partly force the metal into shape. Use an oil-hardening steel. The readily available silver steel is quite unsuited for threading with screw plates because of its resistance to deformation.

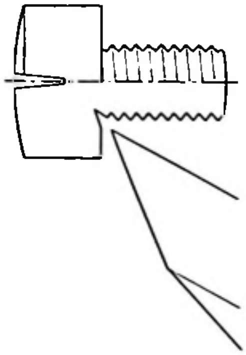
Keep the shaft well lubricated and withdraw it at each full turn to avoid tearing the thread. It will be useful to keep a firm pressure against the back of the plate to help its advancement. Failure to do so will result in poor threads of the form illustrated in Fig 47. Too much pressure will tear the thread. Here again experience is the only guide to success. After the thread is formed with the cutting hole, the duplicate thread in the plate can be used without pressure to complete the final form of the thread.



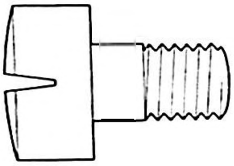
49 Tap made from screw plate

File two flats to bring the thread to a flat taper leaving the end approximately one-third of the diameter, as shown in Fig 49. Now reduce the width at the end for the starting threads, and finally relieve the back edge of the starting threads only. Harden the tap in oil and temper to a pale-yellow colour. After hardening dress the two flats with a sharp oilstone slip to remove the burr from the file and ensure a keen edge. The tap is now ready for use but it should be noted that the thread of the tap is the same size as the thread in the screw plate and consequently a screw made with the plate will not freely enter a hole threaded by the tap. This can be rectified by polishing the screw thread.

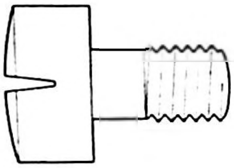
These plates are particularly useful for replacing screws in old watches. The pitch and diameter of the required thread in the plate can be ascertained by screwing a piece of hard wood into the hole.



50a Preparing the corner before threading



50b Diameter of shank correct



50c Diameter of shank too small

Close Threading

When making screws that require threading up to the head it is necessary to use a die without starting threads. Sometimes the die can be reversed and the back face used to continue the thread close up to the head of the screw. Before using a die in this way remove the corner of the screw thread with a pointed graver as illustrated in Fig 50a. This will allow the die to meet the underside of the screw head without risk of chipping the die head.

If the die cannot be reversed then a finishing die must be made from a piece of steel plate. Because the tap diameter is larger than the thread produced by the equivalent die it should not be passed right through the finishing die. When the screw thread enters the finishing die without freedom the tapping has gone far enough and the die can be hardened and tempered. The thread in the die will be very slightly tapered due to the tapered starting threads of the tap. Apply the larger side first to the screw thread and, if necessary, follow with the other side to complete the thread close up to the head. Pressure must be kept on the back of the die to prevent resistance to the die damaging the remainder of the thread.

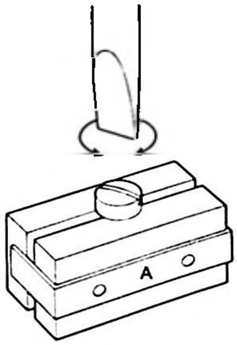
When it is no longer necessary to continue the thread up to the head, the unthreaded portion should be left oversized and finally reduced to the diameter of the thread, as shown in Fig 50b. If the whole length of the shaft is reduced to the thread diameter and left partially unthreaded, as in Fig 50c, the screw will have a bad appearance and the unthreaded portion will be difficult to polish neatly.

Polishing Screw Threads

After hardening and tempering, screw threads are polished with oilstone powder mixed to a wet paste with oil. The screw can be held in the lathe when the shape of the head permits. With a sharp graver take a fine cut from the underside of the head to produce a smooth finish and clean the corner of the thread or shank. Shape a piece of peg-wood to a blunt knife-edge and load it with the paste. With the lathe turning slowly in reverse apply the wood to the thread with a light pressure. As the wood travels along the thread its acting surface will be grooved to fit. Each time the wood reaches the end of the thread repeat the application until the finish is satisfactory.

For screws that cannot be held in the lathe use two pieces of wood charged with paste to hold the screw thread, as shown in Fig 51. Insert the whole length of the thread and squeeze the wood together to form an impression of the thread in the surface. With the pressure reduced to ease the friction use a screwdriver to turn the screw backwards and forwards for a complete turn until the desired finish is achieved. When large screws are polished in this way the wood can be prevented from rolling by a metal stop fixed to one piece of wood as shown in Fig 51 at *A*.

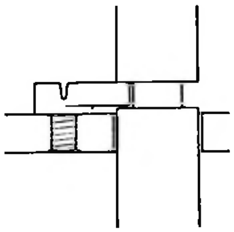
For fine threads and soft metal threads use diamantine, which is also used on larger threads after oilstone paste when a high degree of polish is required.



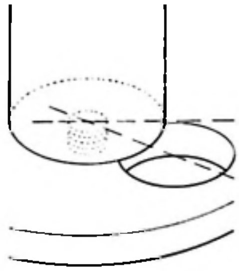
51 Polishing a screw thread

Shoulder Screws

Shoulder screws are used when freedom of the secured component is required after the screw is tightened. There are two basic types: one which revolves with the component, and one around which the component revolves. The former are used mainly in very old repeating mechanisms to retain pivoted components, as shown in Fig 52. To make them, form the thread as described earlier but do not part the screw from the rod. Be sure that the underside of the head is true and flat, for no alteration can be made to it after the screw is finished. Screw the rod into the component and tighten firmly with the fingers. Make a small mark on the rod to the left edge of the pivot hole to indicate the locking flange position, as in Fig 53. Return the rod to the lathe and part off the screw. Cut the slot at 90° to the mark at the edge and file away the unwanted portion of the head to the desired shape. After hardening and tempering, polish the thread which will be sufficiently reduced by the polishing to bring the centre of the locking flange to the centre of the bearing hole when the screw is tightened in the component, as in Fig 54.

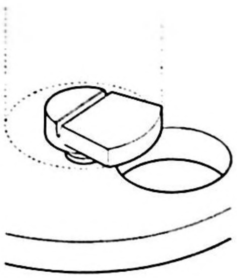


52 Shoulder screw for revolving component

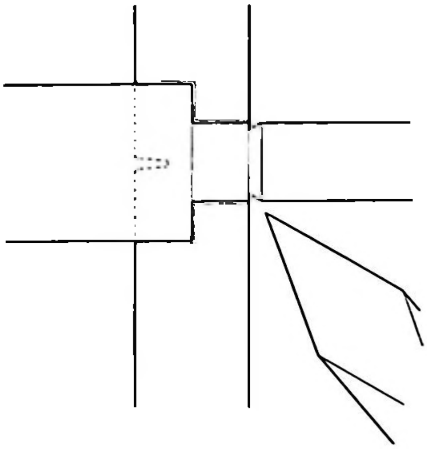


53 Orientating the flange

The second type of shoulder screw is used principally for transmission wheels and pawls. To make them, turn the rod to fit the component as shown in Fig 55. Make a mark with the graver close

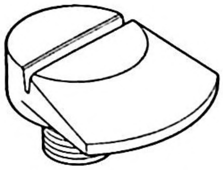


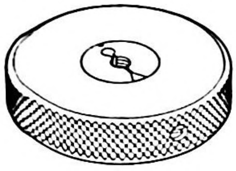
54 Completed screw cut from the rod



55 Shoulder screw to locate a revolving component

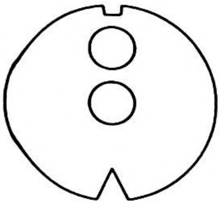
up to the face of the component. From the mark reduce to the required diameter and length, and form the thread. Use a finishing die to clean the corner of the thread. Try the rod with the component in the watch plate and check for freedom and fit of the wheel. If all is well the wheel will be free and without shake on the rod. If it is tight increase the length of the shoulder gradually until the fit is correct. If it is loose reduce the length of the shoulder and re-apply the die to ensure a clean corner to the thread. Examine the surface of the plate to ensure that the shoulder leaves a circular mark after the rod is screwed in tightly. If the mark is not a complete circle the shoulder is not sitting properly and the fit will change when the screw is completed. When satisfied with the fit return the rod to the lathe and part off the screw. All that remains is to cut the slot, harden and temper and finally polish the thread and shoulder. If the shoulder screw is to be used as a case screw, as in Fig 56, mark the head as described for Fig 54 before cutting the slot and filing away the unwanted flange.

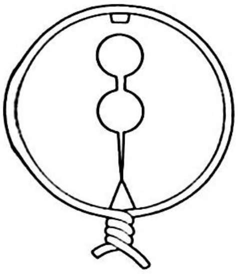

56 Shouldered case screw

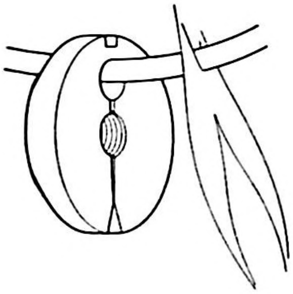

57 Adjustable die for balance-rim screws

Friction-Fitting Balance Screws

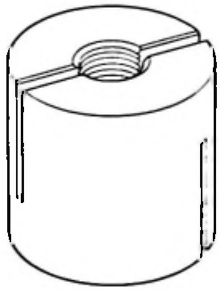
Quarter-timing screws for balance wheels need to be a firm friction fit so that after adjustment they will not change their position. If a standard tap and die are used to make the threads the screws will be too loose. The adjustable die illustrated in Fig 57 will enable screws to be made to fit the threads produced by standard taps correctly. Made from oil-hardening steel it is turned in the lathe to fit the standard die holder. Mark the centre with a pointed graver to form a conical entrance equal in diameter to the full diameter of the tap to be used. Drill the hole and cut the thread. If the cone is correctly sized it will form the starting threads of the die. The drilling and threading should be done in the lathe to ensure that the thread is square to the face of the die. Scribe a line across the diameter and drill a hole on one radius. Make a notch at the edge and file a 'V' opposite it to accept the screw in the die holder. The die will now be as shown in Fig 58 and ready for final slotting with a circular saw in the lathe. After slotting tie a piece of stout iron binding wire around the circumference of the die and twist it tightly to close the slot and reduce the size of the thread, as in Fig 59. Harden the die and remove the wire, and it will be noticed that the slot has remained at the closed setting imposed by the wire. Brighten the flat face with a buff stick and temper on a flat plate to a light-yellow colour. Finally hang the die on a piece of brass wire passed through the flexing hole, as shown in Fig 60, and heat the wire until the edge of the die becomes a light-blue colour.


58 Adjustable die ready for slotting


59 Adjustable die ready for hardening


60 Tempering the flexure point

The die is now ready for use and when fitted into the holder the notch opposite the slot will prevent it turning and the clamping screw can be used to open the thread to the required setting. If the slot is opened to parallel then the thread will be at the standard tap diameter. If the thread thus formed needs to be reduced return the screw to the die and screw fully up to the head. Now slacken the clamping screw and withdraw the thread with the screwdriver. If it will not withdraw with only slight friction then the clamping screw has been slackened too far and must be screwed back a little. The amount the thread needs to be reduced to achieve the correct friction fit is immeasurably small. Attempts to return the screw to the die without it being opened after adjustment will result in the die cutting the thread when a compressing and burnishing action is needed. Keep the die oiled in use and never attempt to overcome excess withdrawal friction by extra pressure on the screwdriver, for this will certainly result in a broken thread. The exact fitting of an adjustable timing screw is work that cannot be hurried and its reward is the ease with which the balance can be brought to time in the vertical positions.

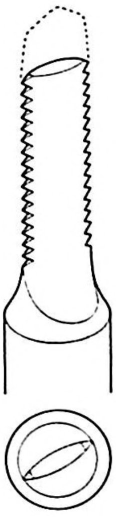


61 Spring friction quarter nut

Quarter-Timing Nuts

Timing nuts running a friction fit on fixed screws are used in chronometers and some watches. These can be closely fitted to the screws using the methods described above but, because the thread is longer than the screw thread in a balance rim, the friction is introduced by slitting and springing the nuts, as in Fig **61**. After threading the nut the slots are sprung together between wood chops until the friction is as required.

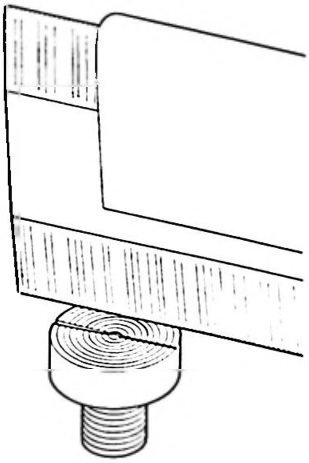
Taps and dies for the left-hand threads are not readily available from tool shops although they are manufactured in standard sizes. In an emergency a left-hand die can be made from a right-hand tap and subsequently left-hand taps made from the die. Break off the starting threads of the tap and grind the edges of the flats to the shape illustrated in Fig **62** and form the starting threads for a left-hand rotation. The remaining points of the thread will have very little of the right-hand helix left at the root. Some pressure will be required to advance the tap against the remaining right-hand helix, but once the thread has started the tap will advance without pressure and form the thread. It may require more than one attempt to produce a good thread for a die but once this is achieved and the die hardened further left-hand taps can easily be made.



62 Tap for left-hand thread

Slotting Screw Heads

Screw head slots for mass-produced screws are cut with a slitting saw and consequently have a square bottom to the slot. When making screws the knife-edge file should be used to produce a better and safer slot. Turn the screw head to the required diameter but leave it a little higher than will finally be required. This will allow for cleaning up the top surface if the slot is started inaccurately. With the screw thread held in the pin vice, locate the file by a light cut at one edge. Lower the file to touch the centre of the head as indicated by the turning marks from the graver. When satisfied that it is exactly at the diameter, tip the file again to start the cut from the original mark. With a few strokes gradually lower the file to start the cut lightly across the head, as in Fig **63**. At this stage the mark should be carefully examined to ensure its accurate location at the diameter. If incorrect, tip the file again to the original cut at the edge and re-lower while cutting to the desired position. Continue the cut to the required depth while watching to ensure the cut is kept level



63 Screw slotting file

with the underside of the head. When almost deep enough turn the pin vice on its side and sight the file exactly level to finish the slot. The close fit of the file in the slot will hold it vertically to the thread while finishing horizontally with the file. The head can now be reduced to the correct height in the lathe with a smooth file and any false marks will be erased. Remove the slotting burr from the sides of the head and the screw is now ready for hardening.

3

FINISHING STEEL AND BRASS

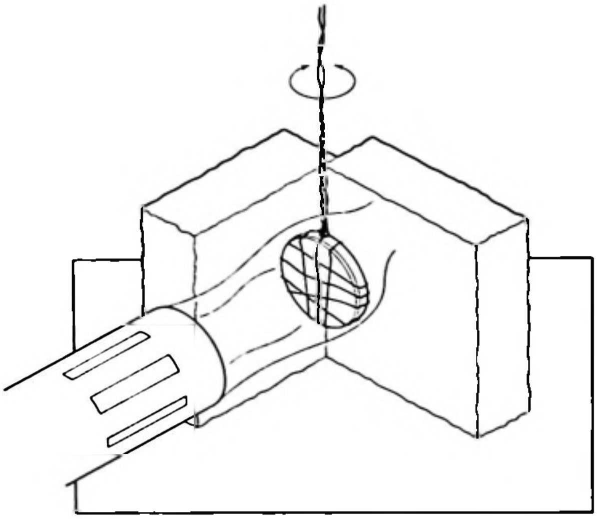
Hardening steel

Steel is hardened by heating to red heat and cooling suddenly. The hardness can be measured by pressing a hard point into the surface and measuring the area of the indentation. This is useful for testing batches of steel used for mass production of components. The watchmaker can learn to assess the characteristics of his steel by testing a small piece before embarking on the work of making a component. It is important to do this with each new piece of steel to avoid errors that could ruin many hours of work.

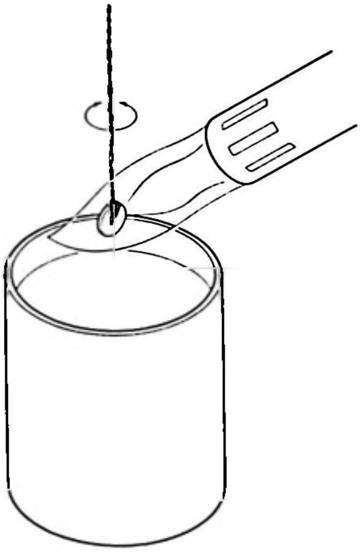
In principle the steel is heated to red and plunged quickly into water or oil. There are many different shades of red heat and some steels need greater heat than others. The watchmaker rarely needs a component to be so hard that it cannot be cut with a metal tool. Experiment with the steel and discover the dullest red that will suffice for hardening. Oil-hardening steels are generally better because oil will cool more slowly than water and this will prevent the component from becoming distorted. Some components will need protection from excessive local heating of the more delicate parts. Heavier components of more uniform density can be held directly in the flame.

In watch factories hundreds of components are heated at one time in oxygen-free furnaces. In this way the pieces are kept clean and free of scale caused by oxidation of the surface. The watchmaker does not usually have this facility and will need to clean the component after hardening. This is not much hardship because most pieces need some form of special finishing for practical or aesthetic reasons. A variable blow-torch with a flame that can reach a diameter of about 20 mm for a length of about 100 mm will suit all the watchmaker's needs. The components are so small that no special heat insulation is needed.

Larger components can be slowly rotated on iron-wire handles which will not harden when quenched. Use charcoal blocks to help confine the heat. Fig 64 shows a copper box suspended by an iron-wire wrapping. This will need more heat than an exposed component and will need quenching in water to ensure sufficiently rapid cooling of the component inside. This form of protection is used to prevent distortion of irregularly shaped, flat components. Keep the coolant close by the torch but never jerk the component hurriedly into the liquid. The movement through the air will induce a drop in temperature at the leading edge that could cause distortion.



64 Hardening box with iron-wire handle

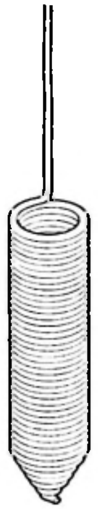


65 Hold small pieces above the coolant

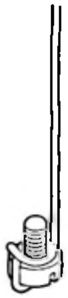
Very small pieces will cool quickly when out of the flame. Hold them immediately above the coolant during heating, as shown in Fig 65. Withdraw the flame before quenching. It is very rare that a component is so small that it needs to be passed from the flame immediately to the coolant. Withdrawing the flame first allows just sufficient time to ensure even conduction of the heat. Binding with iron wire is usually recommended as a means of distributing the heat evenly. This is a tedious business which does not help robust components, and delicate pieces will almost certainly become bent in the binding. Such pieces are better protected by an iron-wire sheath, as in Fig 66. This is made by winding the wire into the form of a closed tube around a pencil or similarly shaped object. The piece can be safely heated until the sheath is red hot and the whole is then plunged into oil. This method will unfailingly harden detents without any danger of distortion.

Plate screws can be held in a loop of iron wire, as shown in Fig 67. Smaller screws are difficult to hold but can be heated in a metal tube suspended from wire, as shown in Fig 68. After quenching, pour off the oil and immerse the tube in the benzine pot to wash out the screws.

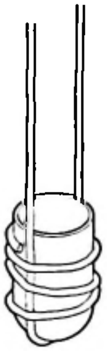
Pinions are covered in soap and supported in a loop of wire, as shown in Fig. 257. Note that to prevent distortion the pinion is loosely held in the loops with the leaves free of the wire. Scaling can be minimized by covering the component with soft soap. This is most easily done by immersing in a solution made by dissolving a tablet of good toilet soap in a little water. Keep this in a sealed jar ready for use at any time.



66 Iron-wire sheath for small components



67 Iron-wire handle for plate screws



68 Metal container with iron-wire handle for small screws

Tempering

It is usual for watch components to be tempered after hardening. The tempering is done by heating, which softens the metal according to the amount of heat applied. This can be measured by the changing colour of the metal as the temperature rises.

When possible one surface is cleaned bright with a buff stick or oilstone slip. The piece is held over the flame on a brass plate until the required colour is reached. If the component cannot easily be made bright a separate piece of bright steel can be laid alongside on the brass plate. This separate steel piece must be of about the same size and surface area as the component to be tempered.

Most watch pieces can be tempered to a medium-blue colour. This will leave them tough enough to resist deformation without being too hard to work with metal tools. Harder tempers for tools or components subject to wear by friction are described later as appropriate. Irregularly shaped or very delicate pieces can be tempered more uniformly in boiling oil, but this should be done in a well-ventilated place.

Finishing Materials

Diamantine Powder

This is a fine, white, crystalline powder, produced during the manufacture of artificial jewel stones. When properly applied to the surface of hardened steel, it will produce a brilliant polished surface devoid of scratches or grain. To achieve a perfect polish with diamantine requires some practice but success will be the more sure if the powder is properly mixed. The powder is mixed with thin oil on a steel or glass plate to the consistency of moist putty. When not in use it must be kept covered and free of contamination by dust. Only a very small amount of oil is required to mix the powder into the desired consistency but this is by no means apparent in the early stages.

Place some of the powder on the mixing plate. A little heap of about 10 mm diameter will be enough. Make a hollow in the top of the heap and put in one drop of watch oil dripped from a rod of about 2 mm diameter. Mix the powder from the edge into the oil until it is no longer fluid. With a stiff, flat, steel spatula, made thoroughly clean on all sides, scrape the powder into a small heap again and press it down flat with the spatula. This process will distribute the oil throughout the powder and at the same time crush down the larger grains. It must be repeated many times until the oil is completely absorbed. At this stage the crushing action of the spatula can be changed to a beating action on the top of each freshly formed heap. If, after five minutes' work, the mixture remains dry in appearance, a tiny drop more oil may be added and the process repeated until the mixture becomes a very thick paste of the consistency of moist putty. In this condition the oil will be thin enough throughout the paste to dry up under the action of the polisher, without which action the best polish cannot be achieved. With practice it is possible to obtain a polish so free of grain and scratches that, when the work is turned to reflect the light away from the eye, the surface looks quite black.

Some of the success of diamantine polishing can be attributed to the quality of the powder. The coarser powders, more crystalline in appearance, usually produce the blackest polish when properly crushed.

Water-of-Ayr Stone

This soft, fine-grained stone is easily cut and filed to shape for special purposes. It is used for flattening and smoothing the surface of brass plates to remove scratches and machining marks. It can be obtained in lengths of square sections of various sizes. A piece about 150 mm in length by about 12 mm square is most suitable for watchwork. When new the surfaces are ribbed with cutting marks and these can be removed with a file while the stone is held under water. The stone should be kept thoroughly wet all the time it is in use. Failure to do so will result in bright spots of metal appearing on the surface of the stone which will scratch the work. The simplest way of avoiding this is to rest the work on a cork block beneath a tap running with a thin trickle of water.

If the work is greasy, as is most likely with a piece in course of making, wash with soap and water before applying the stone. Hold the stone in flat contact while rubbing with short strokes. When the whole of the working surface of the stone is felt to be in contact turn the work through 90° and recommence the stoning until the same soft, smooth contact is felt between the two. Turn the work frequently to ensure flatness of the surface and ensure that the working face of the stone remains in full contact as the tip of the stone passes over the edges of the work. Continue until the surface is quite smooth and free of scratches when it will be ready for whatever final finish is to be applied. The pressure applied to the stone must be just sufficient to keep it in contact with the work. Heavier pressures will cut faster but leave a coarse finish. Do not scrub the surface of the work with a circular motion for this will cause deep, curved scratches.

Bluestone

This has a finer grain than water-of-Ayr stone and does not cut so quickly. In the past it was used principally for polishing brass wheels. Two bluestones are rubbed together with thin, clear oil to produce a thick paste. The paste is applied to the face of the wheel with a wood polisher.

Oilstone

Sharpening stones, manufactured in conveniently sized blocks with a coarse surface on one face and a finer surface on the other, are used for forming cutting edges to hand tools. They are an important workshop tool and should be treated with care if the best results are to be had from them. The surface in use should be kept clean and liberally oiled. The cutting action is improved by regular cleaning with petrol and a stiff brush to remove blackened oil.

Proper use of the oilstone in the early days, when learning to turn, will make the difference between a good and bad turner. The beginner should cultivate the feeling that his use of the stone is part of the process of making a watch and devote to it as much care as he will to the manufacture of the separate components. Once he has mastered the technique of using the stone, with the correct pressure and speed of motion of the tool to be set, the work can be completed with remarkable ease. To a good workman the appearance of a perfectly flat tool face is part of the pleasure of his daily work and is a direct contribution to its quality.

Small slips of various shapes and sizes can also be obtained for small finishing tasks at the bench. They are particularly useful for flattening small, steel components after hardening.

Oilstone Powder

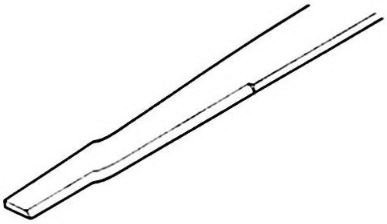
This fine-grained grit is used principally for smoothing the surface of hardened steel prior to applying the final polished finish. To use, mix it with thin oil to the consistency of a thick, wet paste. Do this on a smooth, steel block. Always keep the paste covered when not in use to prevent it coming into contact with the working area of the bench and thus contaminating the work.

Degussit Stones

These hard stones are made from mixed crystals of aluminium oxide and chromium oxide and can be obtained in a variety of shapes and sizes. Smooth or coarse surfaces are made for each shape. They will retain a sharp edge and are especially useful for reaching into sharp corners when finishing steel components.

Polishers for Oilstone Powders

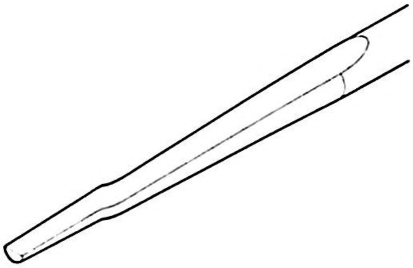
Steel or iron polishers are used for applying oilstone paste. Rolled steel is better able to resist deformation of the sharp edge and will produce a sharper corner to the work. The size of the polisher depends on the size of the work and a correctly sized polisher will enable the surface to be sensed through the polisher as the work progresses.



69 Hard-rolled steel polisher for work with sharp corners

When polishing work in the lathe or turns, long polishers of about 180 mm in length are advantageous in helping to keep the edge square with the face. Three strips of different widths, with the ends prepared as in Fig 69, can be used double-ended, thus making six polishers available for general work. It is not necessary to have a flat face in contact with any shoulder of the work. The edge should be dressed to a sharp corner at an angle away from the flat face. Provided the work is turned cleanly with a sharp graver into the corner, the angled edge of the polisher will reach into the corner and leave it equally sharp after the smoothing action of the powder.

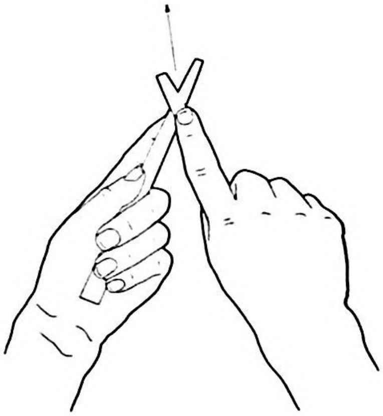
The width of the polisher for general work enables the forefinger to rest on the top surface and keep the polisher in flat contact with the work. For smaller work, such as the short arbors of pinions, suitable shapes and sizes of polisher can be made when required and soon a collection of polishers will be accumulated that will cope with all sizes of work.



70 Steel or brass rod polisher

Round steel wire, filed to a half-round section, will make a good polisher for small work. File the end flat as in Fig 70. This will produce a slight taper throughout the working length, both in thickness and width, which will improve the balance and feel of the polisher. File the working face flat by resting the polisher on the forefinger and stroking the file, as shown in Fig 71. There is no advantage in dressing any polisher by filing across the surface. To do so, especially with a sharp file, is to risk putting the surface out of flat. Filing at an angle across the face will produce a flat surface with the greatest area in contact with the work and with maximum flow of the cutting paste.

The need for a used file when dressing the surface is important. The file should not be so worn as to need excessive pressure to make it cut, for this would produce a shiny surface with poor paste retention. On the other hand a sharp file is liable to rock the polisher by biting too fiercely at the edges, thus producing a rounded surface. The rounding would be too small to see easily but would be enough to make the polisher slow and uneven in action. If a new file is used there is a risk of tiny pieces of hard steel chipping off the file and becoming embedded in the surface of the polisher to cause bright scratches in the work. Choose a file that will cut with a light pressure without biting the surface of the polisher. Such a file will produce a fine, dull-grained surface with maximum ability to hold in flat contact with the work. When prepared in this way the polishing action will be satisfyingly smooth to the touch and the even distribution of the paste will offer a light resistance to the stroke of the polisher.



71 Filing the polisher flat

Only a very small amount of paste is required on the polisher, which is charged by dabbing it lightly on the mixing block. The quantity will be judged by experience but as a general guide, after a dozen strokes, the polisher should display an even covering of smooth, moist, crushed paste with no uncrushed grains at the edges. A further two dozen strokes will dry up the paste and leave the surface of the work with a smooth, bright-grey surface.

Bright ridges on the work and corresponding pressure marks on the polisher indicate badly turned work. To attempt to remove the marks with the polisher will result in the loss of the corner of both polisher and work. The ridges must be turned away with the long edge of the graver before polishing starts.

Do not press the polisher into hard contact with the work. This will simply sweep the powder away to the edges of the polisher and thus leave insufficient to do the work. A light pressure will give the powder time to spread over the whole surface and crush down evenly. As the polisher is moved lengthways over the work it should be biased from side to side to keep the paste flowing over the entire length of the work.

The speed of rotation of the work and the length of stroke of the polisher should be related. Here again experience is essential to produce good work quickly. A general guide is to use strokes of about 40 mm to 50 mm length of the polisher and, when using a bow, three single strokes in two seconds will produce a satisfactory speed of rotation. For small work increase the speed and use shorter strokes of the polisher which, being narrower, will require extra control of the sideways motion. The finish from the oilstone powder is the foundation for the final polishing with diamantine and the beginner must perfect his technique if he is to achieve the final perfect finish.

In addition to these simple, flat, polishers the watchmaker will occasionally need circular laps, facing tools and a variety of small hand polishers for finishing irregularly shaped components. These, and their methods of use, are described and illustrated as required.

Polishers for Diamantine

STEEL The steel polishers used for oilstone dust can also be used for polishing with diamantine. The polisher is charged with the mixed paste by a light touch so that a small amount is transferred to the flat face. The edge will be charged by the spread of the diamantine during the polishing action and this is sufficient to polish a shoulder. The speed of rotation of the work and the length of the polishing stroke are important if the best polishing action of the paste is to be obtained. As when using oilstone dust, a polishing stroke of 40 mm to 50 mm and a speed of rotation equivalent to three single strokes of a bow every two seconds will serve as a guide to the beginner.

Use a light pressure on the polisher to allow the diamantine to spread and crush evenly. Do not keep the edge of the polisher in contact with the shoulder of the work but allow it to touch on each third or fourth stroke only. Allow the polisher to wander along the length of the work to prevent the formation of circular scratches. The condition of the surface of the work can be seen as the polisher is moved sideways during this action and, if the pressure and speed are correct, it will be covered with a black, moist paste. As the polishing progresses this paste will dry and leave a smooth, bright, polished surface. At this moment the face of the polisher will be quite dry and covered with a thin skin of exhausted paste. If the work is not satisfactorily polished the polisher cannot now improve it without first being cleaned and re-charged with fresh paste. Further rubbing with a dried polisher will cause the surface to roll into hard lumps that will scratch the work. The best polish is obtained when the surface is free from scratches at the moment the polish dries.

BELL METAL Even when using proven diamantine with correct pressures and speeds a perfect polish cannot always be obtained with a steel polisher. The type of steel used and the degree of hardness of the work can influence the quality of the polish and may call for a different polisher. Bell-metal polishers can be used when steel is unsuitable. Some grades are harder than steel and will keep a very sharp corner which makes it particularly suitable for polishing in the turns or lathe. A sharp file is needed in dressing the surface, with the polisher resting on the finger, as shown in Fig 71.

Bell metal is a copper and tin alloy and when rubbed on steel it will not so readily mark the surface by welding at the pressure points, as can happen when two steels are rubbed together. This, combined with its resistance to deformation at the sharp edge, makes it ideally suited to polishing tempered steel. It should be used in exactly the same manner as a steel polisher.

BRASS Free-cutting brass rod filed to a half-round section, similar to that illustrated in Fig 70, will quickly produce a flawless, final polish to small pieces such as balance staffs, wheel arbors and steady pins, etc., that have been brought to a good surface with the steel polisher. Useful rigid polishers can be made for glossing the bevelled edges of small components by soldering a strip of zinc to the flat of the brass rod polisher.

ZINC Zinc is used also for polishing flat surfaces. Two pieces, one about 75 mm square and one about 150 mm square, will serve for both small and large work. Prepare the surface by filing flat with a file well charged with french chalk to prevent clogging and consequent scarring of the block's surface. Finish with water-of-Ayre stone under running water. After use the skin of exhausted polish can be wiped away with a cloth moistened with benzine and the surface re-used.

TIN Tin polishers are used for gold, brass and other soft metals but are equally useful for polishing large, steel surfaces. Because the metal is very soft and lacks resistance to bending the polishers need to be quite large and are therefore heavy. A useful size for polishing wheels, etc., while they are resting on a cork block, would be 120 mm long by 15 mm wide by 5 mm thick. This can be formed by pouring the molten metal into a plaster mould of suitable dimensions. While molten in the ladle, remove the scale and impurities from the surface before pouring.

Tin polishers are not suitable for polishing up to a corner, for the edge will soon become deformed. Only the face need be prepared by filing flat with a large, coarse file and following this with a worn, smooth-cut file to remove the scoring. A lighter polisher for use when polishing mounted wheels in the turns or lathe can be made by laying a piece of hard, flat brass in a smaller mould and then pouring in the molten tin. The brass will add stiffness to the polisher to prevent bending under pressure.

WOOD Willow-wood can be used for polishing mounted wheels and will quickly produce a bright polish. It is important that the face of the wheel is quite free of scratches before using willow for the extended use of wood will put the surface out of flat by rounding it towards the teeth.

Burnishers

Burnishers are files with very fine cutting surfaces generated by rubbing them on coarse emery paper or a piece of hard wood covered with emery powder mixed with oil. It is important that the corners are kept sharp and square during sharpening, especially when they are used for polishing pivots with square shoulders.

Small burnishers are easily made to any convenient shape for polishing the bevelled edges of small components or improving the sharpness of pierced corners. Keep liberally oiled in use to prevent the surface clogging and scratching the work. Silver steel is excellent for this purpose. File the steel to the required shape and leave the working surfaces with a cross-filed surface. Heat to bright red and drop into water. Sharpen the filed surfaces with emery paper wrapped around a curved surface to prevent the edges rounding and the burnisher is ready for use. Alternatively lay the burnisher on a piece of cork and rub cross-ways with a coarse oilstone. This will generate a good, sharp, flat surface.

Sapphire Files

These are often recommended for use as pivot files and, used with plenty of oil, will certainly reduce a pivot diameter very quickly. They easily suffer from chipping at the edges when they will leave a ridge at the root of the pivot. The edges can be sharpened only on a diamond lap.

Because the sapphire is brittle and easily broken it should be kept short; about 20 mm in length will allow a thickness of about 2 mm tapering to 1 mm for a width of 3 mm tapering to 1.5 mm. It should be cemented into a thin handle of about 100 mm in length and fitted with a cap to protect the burnisher when not in use. It is really hardly worth the trouble of preparing and a steel burnisher will produce a better result just as quickly. If a pivot needs more reducing than can be achieved with a steel burnisher or an iron polisher the work will be more satisfactorily done with a graver in the lathe or a pivot grinder.

Polishing

Components made in the lathe or turns usually require polishing as the work proceeds. The methods used are described under the appropriate heading for the component and consist entirely of polishing turned surfaces and shoulders while the work is revolving.

Irregularly shaped pieces will sometimes need to be revolved but for the most part can be polished while stationary, either underhand or held in the hand while the work is done by the polisher.

Swing Tools for Polishing

Swing tools were much used at one time for polishing flat the many facets of irregularly shaped components and especially spring detents. Essentially the tool is a pivoted jig capable of holding the surface to be polished level with the centre of motion of the pivots. As the polisher is raised or lowered with the movement of the hand the tool will tip to keep the work flat to the polisher. An example of such a tool, set up to polish the impulse face of a roller, is shown in Fig 301. Note that the surface to be polished is set in the clamp level with the pivots. The tool can be pivoted in the turns or, as was more usual, in a bracket held in the vice.

In days gone by watch and chronometer makers specialized, for reasons of economy, in one particular branch of their craft. As a result it was possible for a workman to develop swing tools and jigs especially adapted to his work. With their aid he could polish quickly, and without risk of mishap, the separate flat surfaces of the piece in course of finishing. No doubt the men who used them were quite capable of polishing a surface flat and square without them and it may be that the speed with which the work could be executed was the principal factor in their use. It is certain that if a man can produce a perfectly polished surface he is sufficiently experienced to be able to do so without the aid of a swing tool. To be properly useful the tool needs to be well made and its construction will take longer than the time taken to develop the ability to polish the surface without it. I do not regard them as essential to watchmaking and believe that excessive use of such tools may have been responsible for the mechanical squareness seen in so much late English work.

Mounted Brass Wheels

These need both revolving and underhand polishing. First polish the spokes with hard wood cut to reach into the corners and charged with rouge. Rouge can be bought in blocks for use on polishing mops. Scrape flakes from the surface and mix into a thick paste with oil.

The free-hand use of the polisher to the spokes and inner rim will give a rounded edge to the work. For nineteenth-century, Continental work with curved bottoms to the spokes the rounded edge reflects the style of the spokes to give a pleasing effect. It does not look so convincing with English straight spokes and should be kept to a minimum.

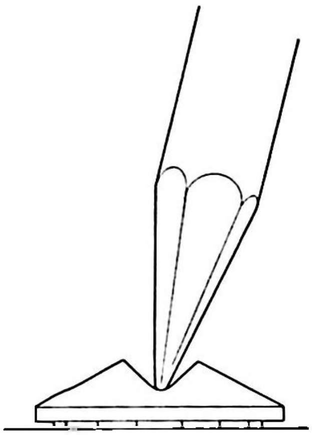
Polish the faces of the wheel with wood polishers and bluestone paste or rouge. The wheel is pivoted in the turns and rotated with a bow. Both strokes of the bow are used. Rub two sticks of the stone together with oil to produce a smooth paste. Prepare the polisher so that it is flat and smooth. A file is usually recommended for this but is inclined to file a curve into the polisher so that the wheel polishes more quickly at the edges and becomes domed. A carpenter's small finishing plane will produce a flat surface quickly. Hold the polisher in the vice and make one steady pass over the surface to be cleaned. For small polishers grip the plane bottom-side-up and draw the polisher over the blade.

Boxwood will produce a flat polish but soon becomes charged with brass and causes scratches. Do not allow the polish to dry before the work is finished. A dry polisher will immediately become charged with brass, a condition which is easily seen in the form of bright, brassy streaks on the surface. These must be removed before continuing the work.

Willow-wood is close-grained but softer than boxwood. If used too vigorously it will cause the teeth of the wheel to become rounded at the edges. A good compromise is to use boxwood to make the surface smooth, and willow to finish to a polish.

Diamantine should not be used lest it becomes embedded in the teeth when it would cut the pinion leaves. Work the bow at about two strokes per second with the polisher moving in the opposite direction. Clean the surface with bread kneaded with oil and finally wash in benzine and dry in warm, boxwood dust.

If the wheels need a circular grain this can be applied with a stick of water-of-Ayr stone, lubricated with oil, or pumice powder and oil on a wood polisher. Water can be used for this. Wash the finished component in clean water, and finally rinse in methylated spirits to absorb the water. Dry in warm, boxwood dust.



72 Polishing small wheels on the tin block

Unmounted Wheels

After polishing the edges of the spokes lay the wheel on a flat, cork block and polish with wood. Turn the block through 90° after every half-dozen strokes of the polisher. When one side is completed clean off by washing in benzine. Wash also the surface of the cork with benzine on a brush. When dry smear the surface with beeswax. Lay the wheel on the beeswax and polish the second side. The beeswax will hold the wheel stationary and prevent the polished surface becoming scratched. Clean off with benzine and dry in boxwood dust.

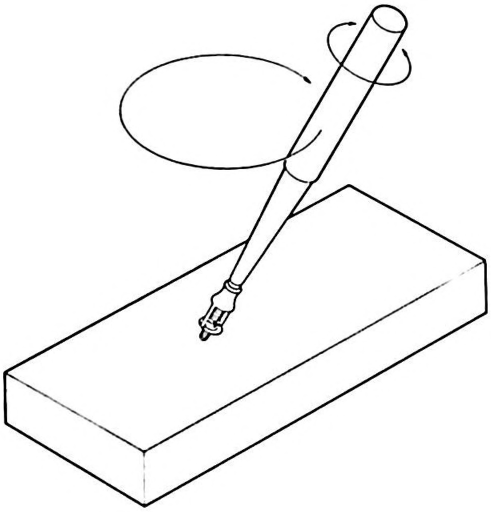
Use a tin polisher for escape wheels. Prepare the surface with a fine file and finish with waterstone under running water. Use rouge or fine, moist diamantine, both of which will produce a brilliant, flat surface. Alternatively the wheel can be polished underhand on a tin block, as shown in Fig 72. Cement the wheel with shellac to the disc with sunken centre to bring the point of the rod low down to the surface of the wheel. Move the wheel with a circular motion of the rod over the area of polish until the surface contact is smooth and silent. Detach the wheel by boiling in methylated spirits.

Wheels must be thoroughly washed after polishing to remove all traces of paste that could mark the pinions of driven components. At one time this was done most effectively with bread kneaded with oil into a dough. Proprietary tacky materials are now available and do the same work more conveniently.

Screws

To polish the end of the thread hold the screw in a lantern holder, as in Fig 73, and rub on wood charged with diamantine. Rotate the holder between the fingers while sweeping the length of the wood.

The holders are made for broaching the pipes of seconds hands and need to have the hole in the thread plugged when very small screws are being held. The heads can be polished by the same method but with the thread held in a pin vice. Alternatively they can be polished while spinning in the lathe.



73 Polishing the ends of screws on a wood block

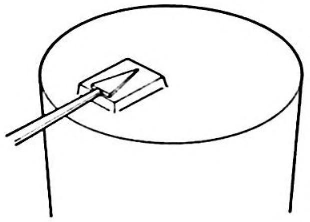
Polishing Hands

Polish the shank or needle of the hand first. Ensure that the corners are quite sharp from the clean edge of the finishing file. Unsharp corners will take on an exaggerated appearance after polishing.

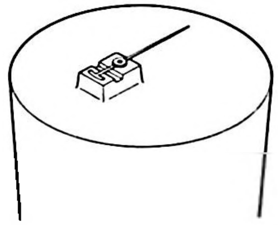
Use iron polishers with oilstone paste to smooth away the file marks on the shanks of steel hands. Hold the hand by the boss as described when making. Polish with diamantine on a brass polisher. Use a tin polisher with sharp diamantine for gold hands. For both gold and steel finish with fine diamantine on a boxwood polisher.

Smooth the flats of steel hands with iron polishers and oilstone paste. Finish with diamantine on zinc polishers. Use a tin polisher for gold. Rest the work on cork cut away to give freedom to the polisher, as shown in Fig 74. The pipe can be pressed into the surface of the cork. Where there is no projection to hold the work steady smear the cork with beeswax. Press the component on to the wax and briefly lay a warmed burnisher on the surface to make it stick. This method of holding the work is particularly useful for small pieces such as endcaps and spring studs, etc.

Both the boss and counterweight of a seconds hand can be polished at the same time, as shown in Fig 75. This will ensure a single, flat reflection from the polished surfaces.



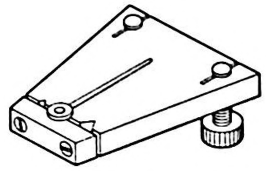
74 Polishing flat on a cork support



75 Polishing separate surfaces plane

Bolt Tool

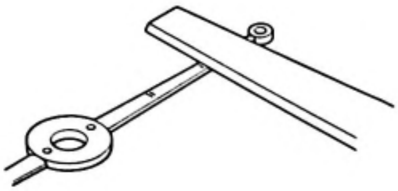
Hand bosses that are too small to remain flat on a cork can be polished underhand while held in a bolt tool, as in Fig 76. This small, general-purpose, polishing tool is often very useful as an aid to flat polishing. Made of brass, it should be thick enough to resist bowing under pressure and shaped as illustrated to allow a light grip between the thumb and second finger while the forefinger maintains a downward pressure. The screws should be hard at the resting tips and slightly domed to prevent scoring the polishing plate. Note that the screws are a friction fit in their threaded holes so that small alterations in height can be made without having to clamp the screw after each movement. The tool is used on the zinc plate with the work clamped under the end plate or waxed to the underside. It is principally used for polishing flat screw heads and delicate, irregularly shaped pieces such as return springs.



76 Bolt tool

Carriage Bridges

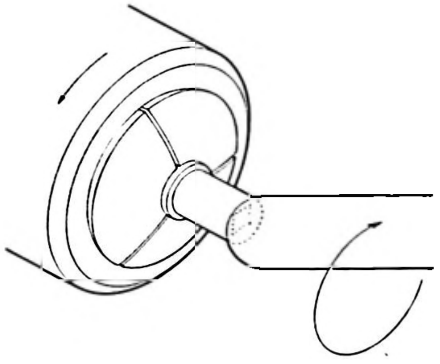
When the length of a curved surface is bounded at each end with a step, care must be taken to a avoid forming a ridge at the centre, as shown in Fig 77. This will occur if the polishing stroke is made with the edge of the polisher in contact with the step. Avoid this by moving the polisher diagonally along the length of the surface. The condition will not be seen by the inexperienced while the work is in progress. Only when the piece is cleaned and light is glinting along the surface will the ridges show. They must be removed with a fine file and the work of polishing recommenced.



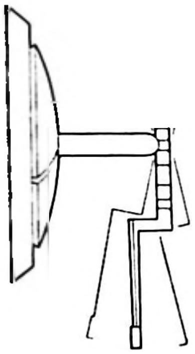
77 Surfaces ridges caused by incorrect polishing action

Hollows

When the component can be revolved in the lathe prepare the hollow with oilstone paste on a brass dome. File the dome to fit the hollow and by observation check the surface as the work proceeds. Move the free end of the polisher in a circle with the finger as the work revolves, as in Fig 78. Finish with diamantine on the same polisher filed to a clean surface. Peg-wood and diamantine will add a final gloss.

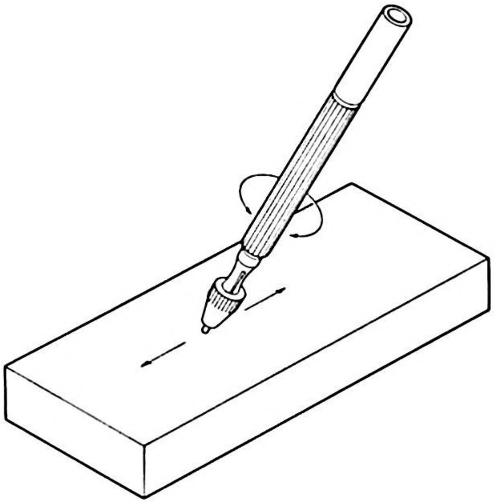


78 Polishing a hollow in a revolving component

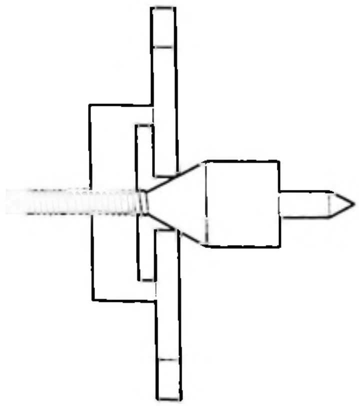


79 Polishing a hollow with a revolving polisher

If the work cannot be revolved put the polisher in the lathe and rock the component while in contact. Fig 79 shows a carriage cock with polished pin sinks. The ends of the steady pins can be polished in the lathe by rotation or by hand in a pin vice, as shown in Fig 80.



80 Polishing the ends of pins on a wood block

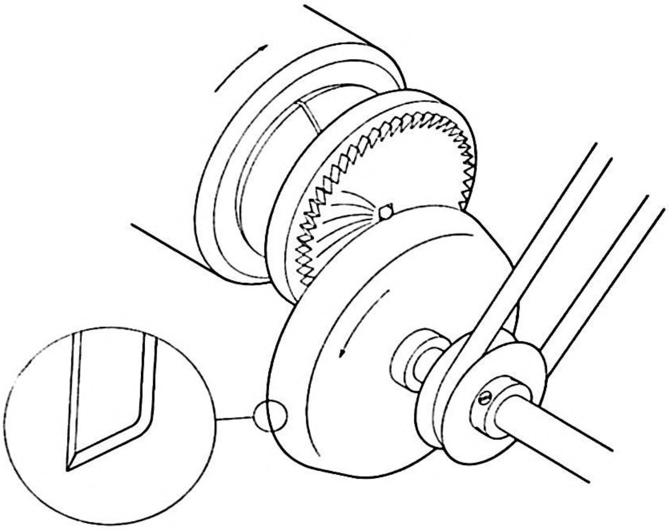


81 Centring arbor for loose wheels

Ratchet Wheels

The teeth of ratchet and winding wheels can be polished in the pinion polishing tool shown in Fig 258. Fit the wheel on to an arbor between the centres. Charge the wood disc with metal polish. The arbor illustrated in Fig 81 is shaped with a cone to keep the wheel concentrically under the hollow nut.

The faces can be finished with a spirally radiating, grained surface with oilstone paste applied with a cupped disc rotating in the opposite direction, as shown in Fig 82. The disc is turned by a supplementary pulley from the lathe drive. Apply the oilstone paste to the face of the ratchet wheel.



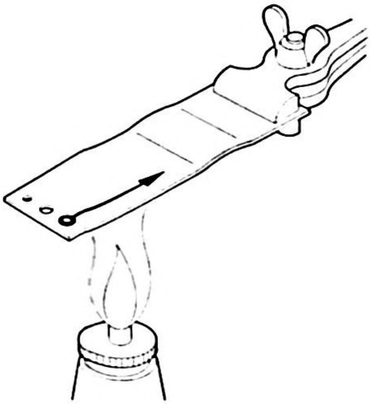
82 Finishing ratchet wheels in the lathe

The faces can be ground to a matt-grey colour with oilstone paste on glass. Put a thin layer of oilstone paste on a flat, glass surface. Lay the wheel on it and with a circular scrubbing motion roll the face of the wheel over the oilstone particles. The rolling action will give a frosted grainless effect to the surface of the steel. Apply only a gentle pressure to prevent the grains crushing into the glass and scratching the steel.

Blueing
Scrupulously clean work is necessary to produce a rich even colour. Complete freedom from draught is essential to uniform temperature rise. Beware that the heat of the bench lamp does not cause convection draughts. Watch the flame of the lamp before starting work. If it flickers and wavers it is in a draught and the colour change will not be uniform.

Hands
Polish the hands overall and wash them in clean benzine until they are quite clean and free from grease. The smallest trace of grease or dirt will cause a patchy colour.

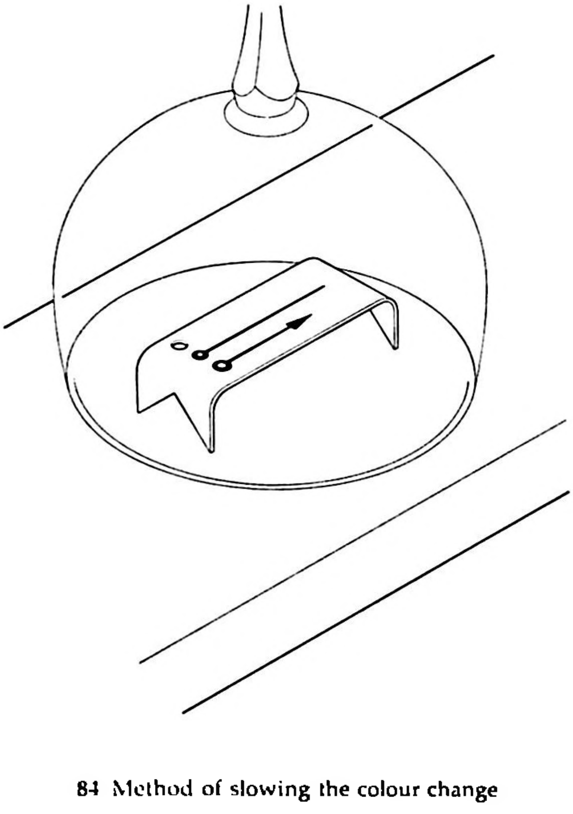
Blue the hands one at a time on a clean brass plate held over a spirit lamp. Use a plate about 100 mm by 30 mm by 1 mm thick. At one end drill holes to receive the extended pipes of the hands. At about 40 mm from the other end, bow the metal into a slight hump. Thoroughly scrub clean with a wire brush before use. Hold the plate in a hand vice above the lamp and tip it so that the flame



83 Blueing on an open plate

cannot reach the watch hand, as in Fig 83. Move the plate lengthways through the flame to distribute the heat along its length. As the hand begins to change colour raise the plate higher above the flame to reduce the heat. Allow only the heat from the plate to reach the hand. The direct heat of the flame on the pipe would instantly ruin the colour. If the colour is uneven move the hand so that the part which is delayed in colour is resting on the hump. This will slow the rate of change at the darker area. Move the hand about as necessary to produce an even, dark-blue colour. The darkest blue follows immediately after purple. Any lighter shade will look cheap and unprofessional and should be rejected. With a little practice in judging the colour and manipulating the hand this simple method will quickly produce perfectly blued hands.

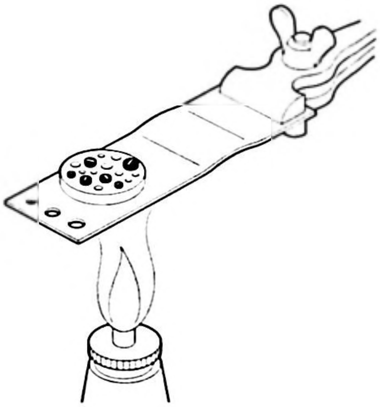
The colour can be produced more slowly if the hand is supported on a stage above the brass plate. Use a gas ring or blow torch to raise the heat, as shown in Fig 84. A glass cover will help to distribute the heat but will not guarantee the uniform production of colour. Any remaining slow patches will need to be advanced with a heated bar. Use a piece of brass or copper rod heated with a blow torch. Hold the hand in the tweezers and touch it on the heated rod at the areas of delayed colour. The hand must be lifted from the heated rod when the colour is purple and then held close until the required dark blue is reached.



84 Method of slowing the colour change

The late Professor David Torrens told me that, as a young man, he had seen Mr. Hood, a handmaker of Clerkenwell, blue his work in the fire of his sitting-room. When he had made enough to cover a brass plate he would rake the embers of the fire into a uniform red layer and place the plate on top. Next to it was a copper anvil to supply the local heat to the areas of delayed colour. The hands were held in contact with the tapered horn of the anvil until the colour was uniform. This is an excellent method of maintaining a controlled range of temperatures running to the lowest at the point of the horn. There are many different ways of heating the work to blue, but that illustrated in Fig 84 requires least equipment and will, with practice, produce a perfect colour.

If the colour becomes too pale or is patchy the work must be re-polished white with diamantine on pith or wood. A complex surface such as the teeth of a ratchet wheel can be whitened by immersion in a solution of 20 per cent hydrochloric acid in water. Unpolished surfaces will re-blue satisfactorily after immersion but polished surfaces must be polished again to ensure an even colour after immersion.



85 Hollow support for blueing screws

Screws

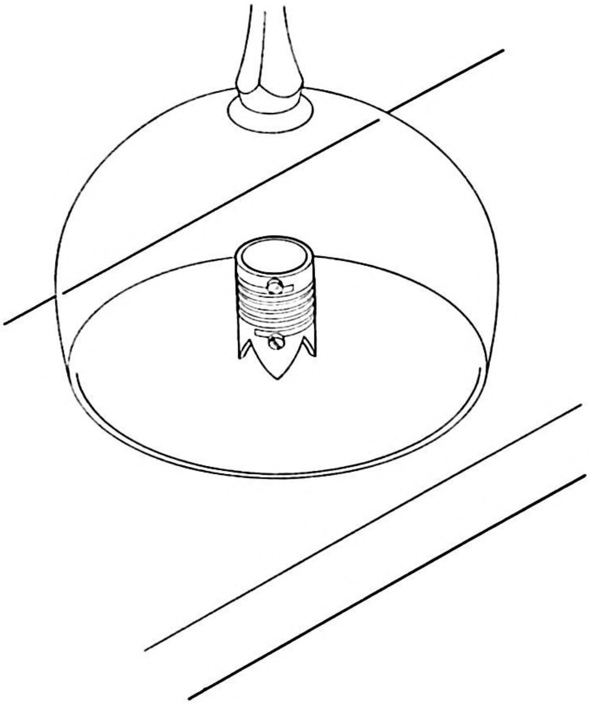
Screws should be given a final light polishing with diamantine on hard pith. Brush thoroughly clean and pay especial attention to the slot and thread. The smallest speck of dirt will cause a patchy colour.

Make a hollow support in the form of a drum of about 1 mm thickness overall. Use as shown in Fig 85 on a plate above the spirit lamp. Lift off the screws that colour early and, when the remainder are deep purple, remove from the flame. Watch closely the last stage of change to deep blue. When the colour is correct, tip the screws on to a clean sheet of metal.

Balance Springs

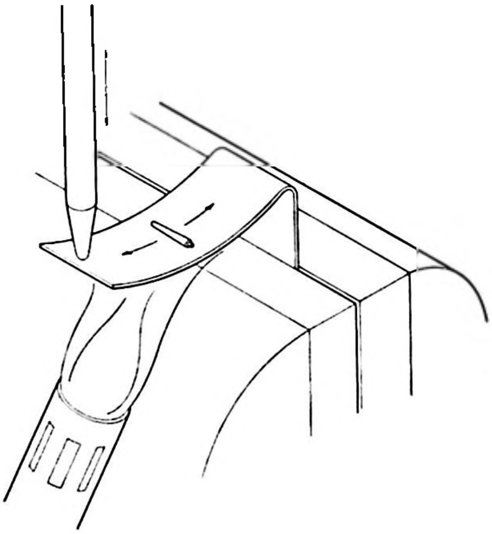
Spiral springs are blued on a flat, brass plate. Thoroughly clean the plate with a wire brush and play the flame over the surface to burn off any acids or grease. It is essential that the colour changes uniformly because low areas cannot be raised. Put a glass cover over the spring to protect it from convection draughts. When it turns a deep-purple colour remove from the heat and when the final colour is reached tip off the plate on to a clean sheet of metal. The spiral will relax slightly during the blueing.

Helical springs are blued on a metal tube. A grooved tube is not strictly necessary but would ensure that the spiral is free from distortion. Cut away the base of the tube to reduce the heat transfer to the lower coils. Thoroughly scrub the tube with a wire brush and pass through the flame to remove acids or grease. Secure the spring at each end as a precaution against the coils relaxing and slipping out of the groove. Use a glass cover as illustrated in Fig 86. Hold over the flame and remove when it turns a deep-purple colour. When the spring is dark blue remove the cover and allow the spring to cool before removing from the tube.



86 Blueing a spring on a ventilated former

Cylindrical items like the shanks of the keys illustrated in colour are blued on a brass plate curved to a hollow surface. Hold a blow torch beneath and allow the shank to roll to and fro in the hollow by flexing the plate with a metal rod, as shown in Fig 87.



87 Distributing the heat in key shanks

4

TURNING

To Make a Balance Staff

The dimensions for balance staffs, pinions and similar pivoted components can be taken from the movement or from a damaged component if it is serviceable. Accuracy is more certain if a dummy component is made by trial in the frame and used as a gauge for axial dimensions of the final component as seen in Fig 590.

Turning in the Split Collet

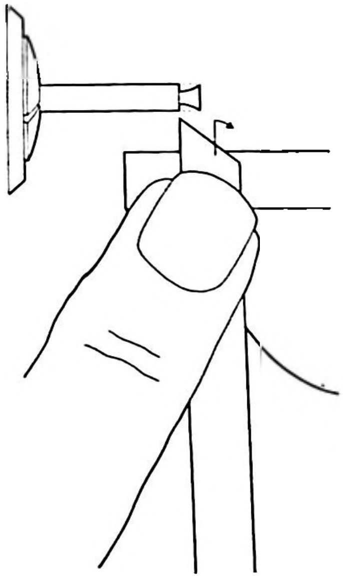
When a balance staff is turned in a split collet in the lathe it must at some stage be turned end for end. This almost inevitably means that there will be some eccentricity between the two ends. The division of the work on the two halves will be at the hub, below the balance seat. The upper pivot, the collet arbor and the balance rivet will be mutually concentric. When the incomplete staff is parted from the rod, as described in the following pages, the point of the lower arbor will be concentric to them. When reversed the lower point can be trued as the headstock revolves. If the condition of the lathe collet and spindle is good the eccentricity at the hub of the staff will be a maximum of 0.005 mm.

Some errors of timing will result from this eccentricity which will need correcting by adjustment to the balance. But as this is always necessary, when the watch is to be submitted for observatory testing, this is not a reason for rejecting the staff or the method of making it. It is important only that there is no relative eccentricity of the two pivots. For this reason the methods described for making the staff demand that the pivots are finished between centres.

An obviously untrue staff is of course unacceptable. When the condition of the lathe or collet allows an eccentricity greater than 0.01 mm, when the staff is turned end for end, the work can be done wholly or partially between centres, as described later.

The staff may be turned from carbon steel, hardened and tempered, or from the blued-steel rod available from material houses. In both cases test the steel for temper. Turn a pivot of about 0.11 mm diameter and to a length suitable for a watch. Grip the pivot in the tweezers and bend it. When correctly tempered the pivot will break off after about 20° of bending. If it breaks earlier the steel will probably be too hard to turn with the extreme point of the graver. If it breaks later the steel is probably too soft to turn between centres. The best condition can be found only by experiment with the heat treatment.

When a new length of steel is used turn away the first few millimetres of length to expose a clean end. Use the graver resting flat on an annealed steel 'T' rest, as shown in Fig **88**. A hardened 'T' rest will allow the graver to slide about so that more control is necessary. With practice its use can help to speed up execution of the work, but the beginner should beware that the point of the graver is not pulled beneath small-diameter work to cause a breakage.


88 Graver resting flat on the 'T' rest

Move the point of the graver forward into the surface of the rod to a depth of about 0.5 mm using a very light pressure to preserve the point. Now urge the graver towards the end of the rod with the tip of the left forefinger to make clearance for the next advancement of the point. Do not exert excessive pressure during this advancement, but rest the point gently against the surface of the rod and allow it to lift the surface of the metal according to the speed of rotation. To reduce the diameter more quickly, increase the speed of rotation and advance the cutter faster both radially and axially, but do not increase the pressure for this will only wear the cutting edges and slow the rate of cutting.

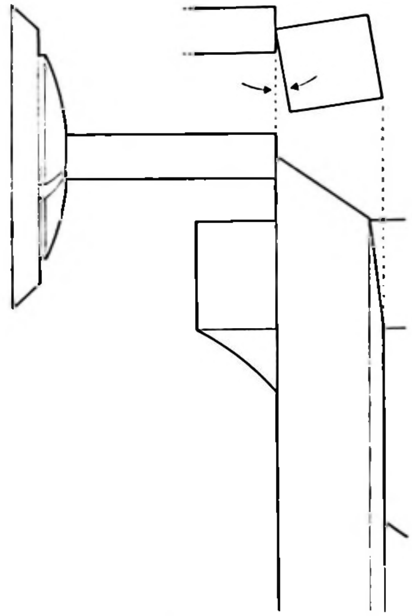
Note that when cutting with the graver flat, the 'T' rest must be kept close to the work to prevent the tip of the graver drawing into the work below the centre line. Do not grip the graver too tightly in the fingers, for this will reduce the flexibility of movement and the sensitivity of the fingers to the pressure applied. In Fig **88** it can be seen that the end of the rod is flat after the unwanted part is removed. This face is formed by the long side of the graver, which strictly is not a cutting edge. It can be induced to cut just as quickly as the leading edges by tipping it to form a clearance, as in Fig **89**, and lowering the handle to bring the point up to the centre line of the work. When the end is finally parted, the face can be smoothed if necessary by inverting the graver as shown in Fig **90**.

Truing the Rod

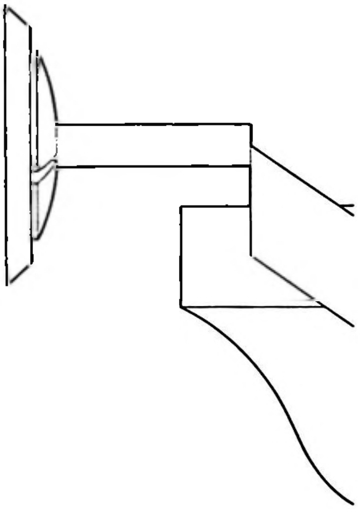
Next reduce the diameter over the exposed length nearly to the required final diameter of the balance hub. The initial stages of this reduction must be made with the point of the graver, as shown in Fig **91**, to correct any ovalness or curvature of the rod. When the rod is true and round bring the graver into full contact to preserve the point and to increase the speed of reduction, as in Fig **92**.

Turning and Polishing the Hub

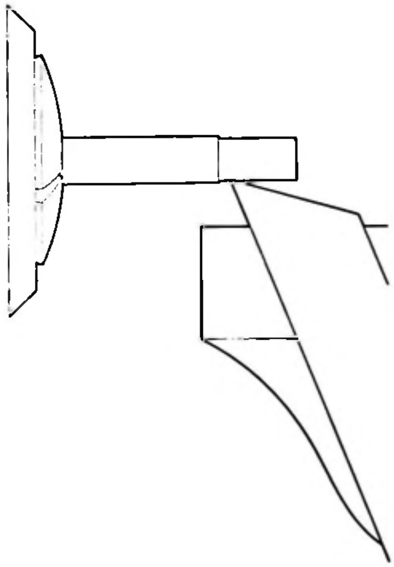
The balance seat must now be turned so that the balance fits on to the arbor without freedom and without binding in order to ensure a full seating against the shoulder, as shown in Fig **93**. If the hub of the seat is to be polished it should be done at this stage. First



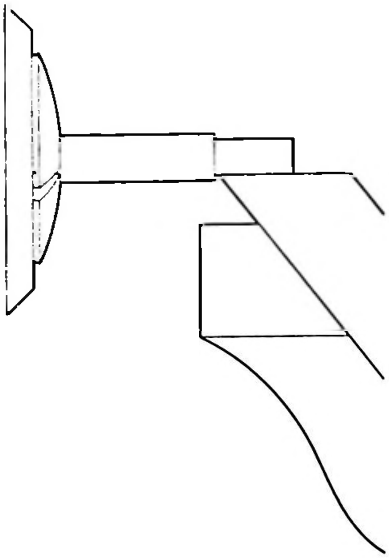
89 Facing with the corner of the graver



90 Facing with the inverted flat graver

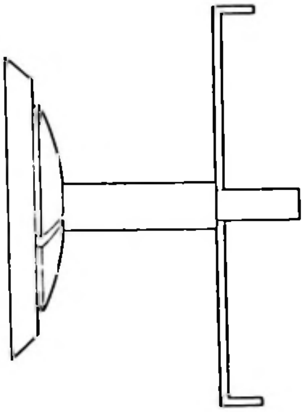


91 Truing cut with the point of the graver

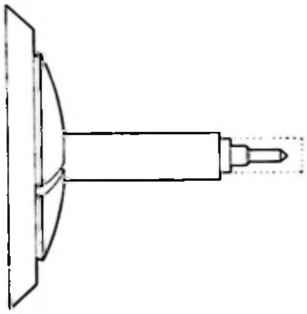


92 Use the broad cutting edge to preserve the point

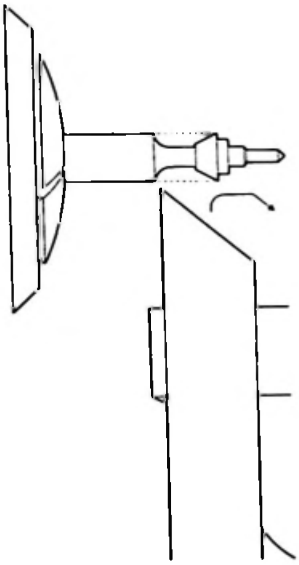
reduce the diameter of the rod nearly to the final diameter of the balance spring collet arbor and further reduce the diameter of the end for the pivot, as in Fig 94. Turn the back slope and make clearance for the polisher, as in Fig 95. The surface of the hub should be smooth and bright from the graver and need only minimum attention from the oilstone polisher. Any grooves or ridges must be removed with the graver before attempting to polish.



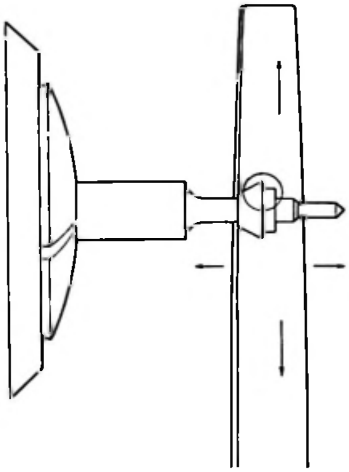
93 Turn the arbor to fit the balance



94 Reduce the end almost to size



95 Turn the back-slope

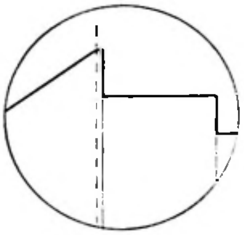


96 Polish the hub

Use the oilstone polisher under the hub so that full contact with the slope of the hub can be seen. Use only a very little paste on the surface of the polisher. The importance of the correct amount of paste cannot be overstressed. An excess will not crush down without extended application of the polisher which will cause the surface of the hub to lose its flatness. After the first few strokes there should be no uncrushed grains left on the polisher. After the first dozen strokes of about 30 mm length of the polisher the surface should show a smooth, black, oily deposit. The surface of the hub will show the same deposit and any bright streaks will indicate the pressure points, showing that the polisher is not in flat contact. Keep the polisher moving over the surface of the work to prevent grooves forming and continue the combined to and fro and sideways motion, as in Fig 96, until the surface of the hub is a smooth silver-grey colour. The work should take only thirty to forty seconds and should be stopped before the oil dries and allows the polisher to score the surface by metallic contact. Thoroughly clean the work of all paste.

Polish the surface by the same method but with diamantine and a bell-metal or free-cutting, brass polisher. Use only a very light pressure on the polisher to allow the paste to crush down evenly and prevent scratches in the initial stages. As with the oilstone paste, only a very little diamantine is required. After the first dozen strokes, the surface of the polisher should be fine, smooth, moist and black with no uncrushed grains of diamantine. After thirty to forty seconds the surface of the polisher should show a polished, black and apparently dry skin. This surface is not completely dry of oil as can be seen from the minutely thin film of paste on the surface of the work. At this stage, stop the work and examine the surface after cleaning with pith. It should be free of scratches and have a smooth, highly polished surface. If any circular scratches are to be seen this indicates insufficient movement of the polisher over the surface. Scratches at random angles may indicate insufficiently sharp diamantine failing to eliminate marks from the oilstone polisher. These can be eliminated by again preparing the polisher and repeating the work. It is useless to continue without preparing the polisher again for this would merely turn the surface of the work brown. This condition is called 'foxing'. If the surface is not improved by the second application then the fault lies with the diamantine.

The most common causes of failure are insufficient crushing of the diamantine during preparation, a paste which is too oily, an out-of-flat polisher and, most frequently, excessive speed of rotation of the work combined with excessive pressure. When the polishing has been completed it will be seen that the sharpness of the corner of the balance seat has been lost. Take a fine cut from the seat to lower the balance and sharpen the edge, as in Fig 97.



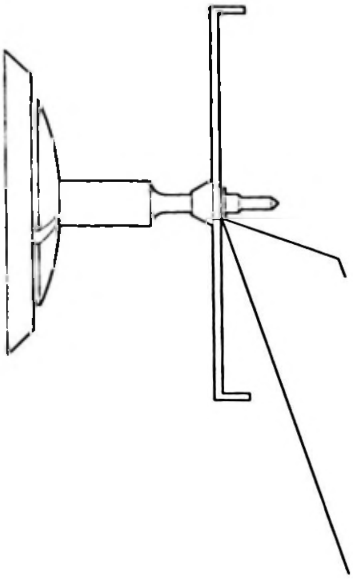
97 Sharpen the edge after polishing

Turning the Rivet

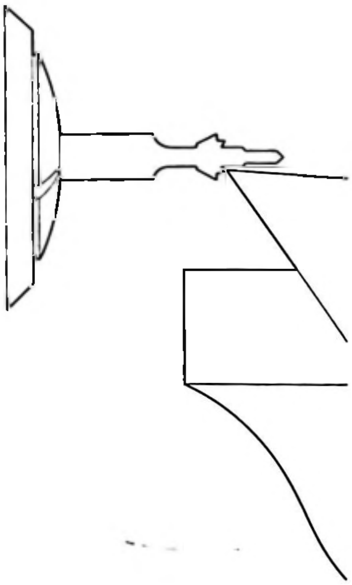
With the balance in position place the point of the graver slightly higher and make a groove to indicate the height of the rivet, as in Fig 98. Turn away the unwanted length and at the same time bring the collet arbor to diameter allowing the point of the graver to undercut the rivet, as in Fig 99.

Fitting the Collet

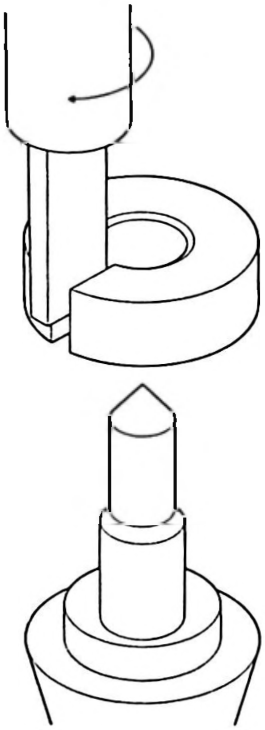
Although the collet is usually split to allow a spring fit, the diameter of the arbor is quite critical if the collet is not to be too tight. To avoid distortion of the collet and possible damage to the spring during subsequent removal the arbor should be polished until the collet is a light, spring-fit easily removed with a thin blade twisted in the slot, as in Fig 100. Turn the arbor to length and bevel the corner to assist entry into the collet. Press on the collet with a punch



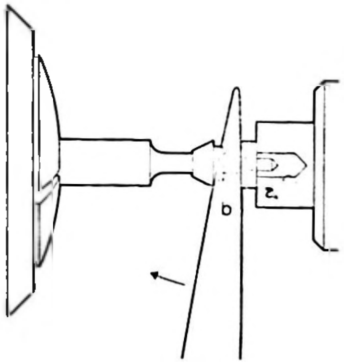
98 Turn the rivet to length



99 Undercut the rivet

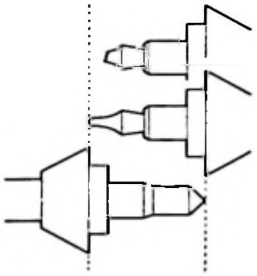


100 Tool for removing the collet



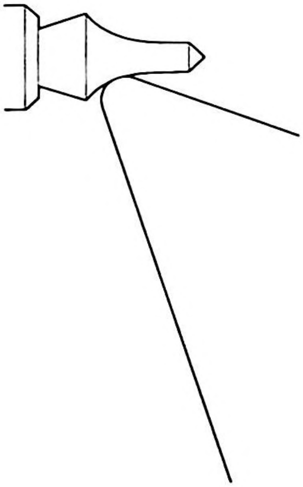
101 Removing an unslotted collet

in the tailstock, as in Fig 101, *a*. If it does not turn smoothly, with sensible friction, it can be prised off with brass tweezers, as in Fig 101, *b*, and the arbor further reduced until the fit is correct. If the collet is a solid English one the arbor must be polished to a slight taper and the collet fitted almost up to the rivet. It is secured by a slight twist, made under pressure to make it sit down on the rivet.

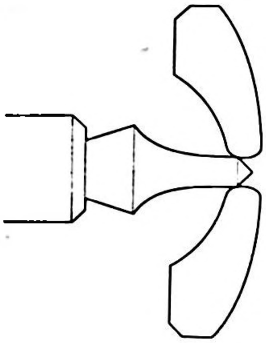

102 Checking the length from the balance seat

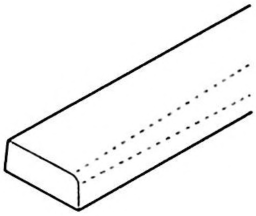
Turning and Polishing the Top Pivot

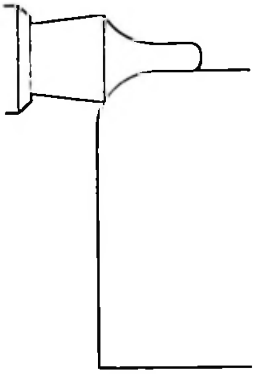
The staff must now be made to length from the balance seat to the end of the top pivot. Use the point of the graver to remove the unwanted end in the manner shown in Fig 88. The length can be determined from the original staff, as in Fig 102. If the pivot is damaged make allowance to bring the new pivot to the correct length. Turn the pivot with a round-ended graver, as in Fig 103, until it will almost enter the hole in the balance cock, as in Fig 104. The pivot can now be smoothed with oilstone paste on a steel polisher and polished with diamantine on a bell-metal polisher. Shape the polisher to a curved edge of constantly decreasing radius towards the tip, as in Fig 105. With a little paste on the curved edge of the polisher find the part of the curve that fits the curve of the pivot when the flat of the polisher is in contact with the pivot, as in Fig 106. The point of contact will be seen as a bright mark on the revolving pivot. Moving the polisher to and fro will allow the changing radius of curvature to polish the curve of the pivot over the whole surface, and at the same time merge the curve into the parallel pivot. The width of the polisher will help to sight it parallel to the pivot but any difficulty in doing so can be overcome with the adjustable support illustrated in Fig 107. Concentrate the action of the polisher on the curve of the pivot by observing the bright mark at the point of contact on the curve. The pivot should not be reduced sufficiently to allow it to enter the hole with freedom. The final finish to allow working freedom will be done later with a burnisher.


103 Turning the pivot

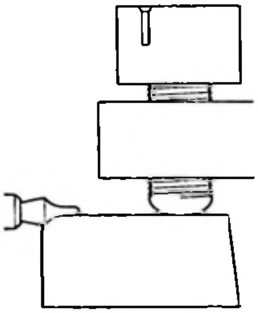
The pivot can easily be reduced with an Arkansas slip but this is not a sound method. Unless the pivot is very nearly to final size the cone will need a shaped stone if it is not to become distorted in shape, and the pivot may become oval. This method cannot be used


104 Use the pivot hole as a gauge

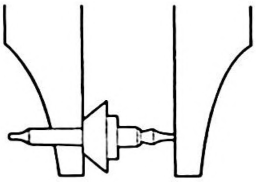

105 Curved edge of the polisher


106 The flat of the polisher in contact with the pivot

when the staff is turned between centres. The delicacy of touch required to turn the pivots with the graver is soon acquired and is essential on the many occasions when it would be impossible to bring the stone up to the work.



107 Adjustable support for the polisher



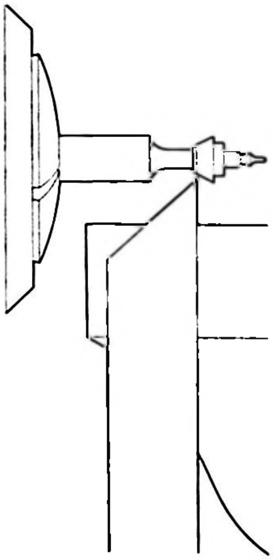
108 Measuring the length of the hub

Preparing the Roller Arbor

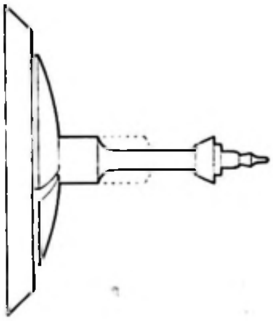
It now remains to turn the hub of the balance seat to length before parting off and turning the lower half of the staff. The length of the hub can be taken from the original staff measured from the underside to the end of the pivot. This will avoid possible multiplication of errors of total length that could occur if the length of the seat only were taken. It can be done by sighting across a gauge, as in Fig 108.

Make a mark on the hub with the graver to indicate a little more than the length required. Present the graver, as in Fig 109, and cut into the polished surface of the hub up to the mark. Check with the gauge and make further cuts with the graver tipped towards the face, as in Fig 89, until the hub is to the correct length. Now clear away the surplus metal, as indicated by the dashed lines in Fig 110, and part off the staff leaving a true point, as in Fig 111. Form the point by working away from the hub, as indicated by the arrow, to prevent the staff from becoming detached before the point is formed.

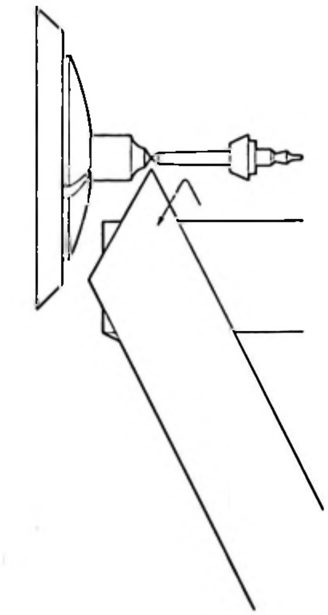
Clearing away the surplus metal below the hub before parting off will leave very little work to be done to the lower arbor. This is important because the staff must now be gripped by the upper or spring collet arbor or, if this is tapered, by the balance rivet. Both will offer sufficient security but it is obviously an advantage to reduce the amount of work to be done when the length to grip is short.



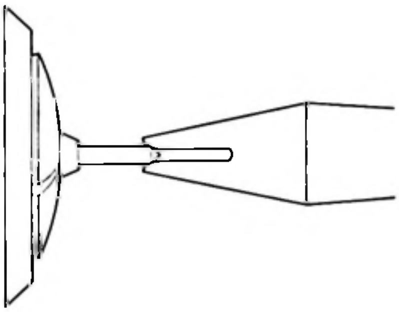
109 Turning the hub to length



110 Clear away the surplus metal



111 Part off to a point



112 Centring the revolving point

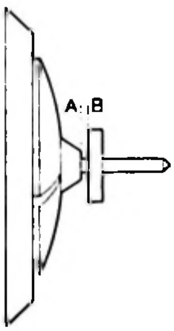
Truing the Roller Arbor

Select a collet by measuring the part to be gripped. The bore of the collets varies by 0.1 mm increments If the measurement falls between two successive collet diameters use the larger size to ensure maximum grip at the collet face.

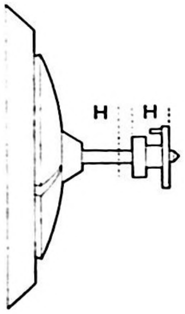
Grip the staff in the collet with just sufficient pressure to hold it in position. Bring up the tailstock and with the staff revolving catch the point with the tailstock female centre, as in Fig **112**. Withdraw the centre slowly and the cone will bring the point to a true centre. Tighten the draw bar to secure the grip.

Fitting a Single Roller

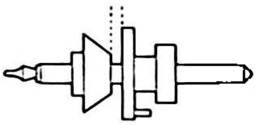
The roller arbor can now be turned and polished. If it is to take a single roller, as for a chronometer or early English lever, taper the arbor slightly with the graver before polishing. Fit the roller with a light finger pressure to a distance of half its thickness from the hub, as in Fig **113**. Measure the diameters at *A* and *B* with a micrometer. *A* should not exceed *B* by more than 0.01 mm. With practice the arbor can be brought to the correct taper without measuring but it is useful to know in finite terms what degree of interference is necessary to ensure a good fit without use of force. If excessive force is needed to fit the roller close up to the hub the staff is likely to be warped and will certainly suffer damage if the roller needs to be removed.



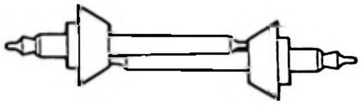
113 Fitting a single roller



114 Fitting the safety roller



115 Fitting the impulse roller



116 Gauging the length of the arbor

Fitting a Double Roller

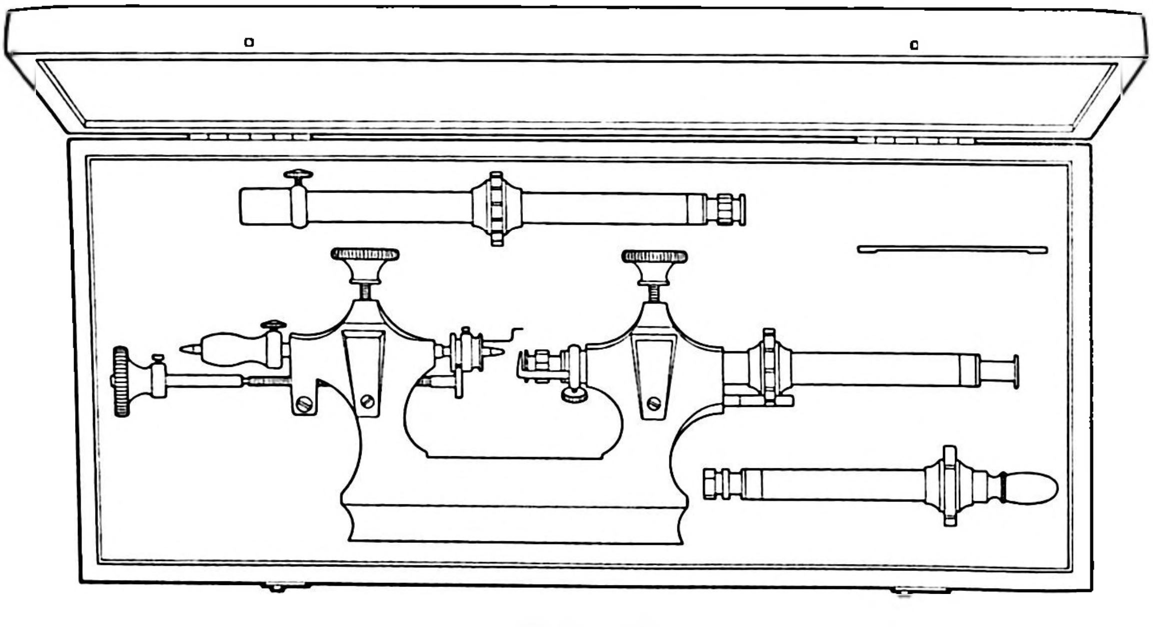
If a double roller is to be fitted the taper of the arbor must conform to the taper hole in the roller. First turn a slight taper to the lower end of the arbor until the inverted roller will fit to a distance from the hub equal to its height, *H* in Fig **114**, plus the thickness of the safety roller. Now turn the upper part of the arbor to a taper that merges into the middle diameter. Do not remove any metal from the middle for this is the correct diameter for the lower part of the roller. By polishing the arbor fit the roller to a distance from the hub equal to the thickness of the large impulse roller, as in Fig **115**. During the polishing the middle of the arbor will be slightly reduced in size so that when the roller is fitted close up to the hub only the upper half of the taper will offer interference while the lower half will simply centre the safety roller. Fitted in this way the roller will be secure, concentric at both ends and, equally important, simple to remove without damage.

Turning the Lower Pivot

Determine the length of the arbor from the original staff, making any necessary allowance for change of length, and finally turn and polish the lower pivot. In Fig **116** it can be seen that as a result of measuring the upper half of the staff from the underside of the hub it is a simple matter to measure the lower half precisely with the old staff as a gauge.

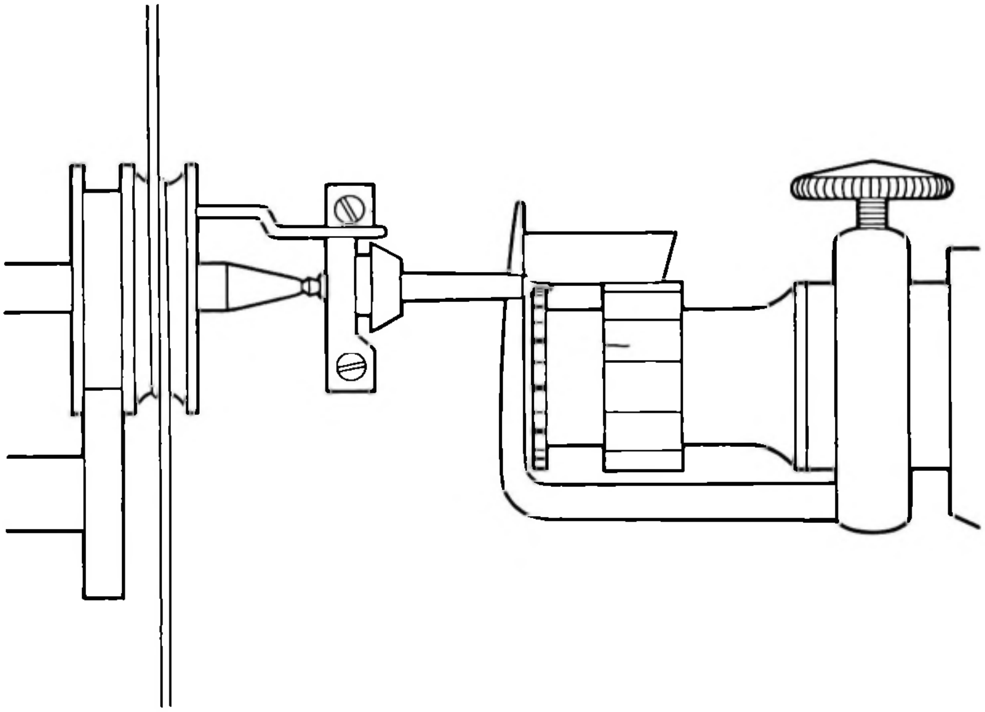
Burnishing the Pivots

For polishing the pivots one end of the staff or arbor is supported in a safety centre while the pivot to be polished is supported in a bed made to take the pressure of a burnisher without risk to the pivot. A



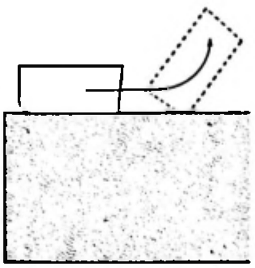
117 Jacot tool

convenient and especially designed aid to polishing pivots is the Jacot tool, illustrated in its protective box in Fig **117**. The left-hand runner has a loose pulley with carrying pin for rotating the work by means of a bow. Some tools have a cord with spring return which is more convenient than the bow. The right-hand runner has a series of flats in the form of a double flange. The innermost flats have longitudinal grooves of varying depths to support the pivot according to size. The backing flange is simply for supporting the burnisher level while it is in contact with the pivot. A safety guard is fitted to this runner which can be adjusted to prevent the burnisher exerting pressure on the curve of the pivot with possible risk of breakage. The staff illustrated in Fig **118** is fitted with a carrier and resting in the runners with the burnisher resting on the pivot and against the guard for right-hand use. Note that the rounded edge of the burnisher does not touch the curve of the pivot and it was for this reason that the curve was polished in the lathe. The length of stroke of the burnisher should be restricted to about 15 mm for a bow stroke of about 50 mm. Use the bow and burnisher slowly at about a single stroke per second and keep the pivot lubricated. With only a light pressure a well-prepared burnisher will quickly reduce the pivot, which should be checked frequently for size.

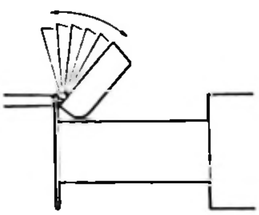


118 Bed runner with safety guard

To prepare the burnisher hold it in flat contact with a coarse oilstone and move it from end to end of the stone without rocking. On the final stroke roll the burnisher on to the rounded edge to merge the flat to the curve, as in Fig **119**.

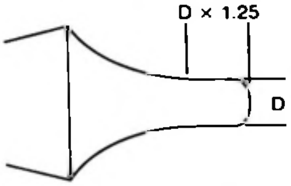


119 Preparing the burnisher

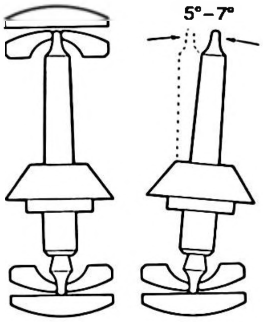

120 Finishing the pivot ends

Burnishing the Ends of the Pivots

Finish the ends of the pivots by changing the bed runner for a lantern runner, as illustrated in Fig **120**, and with short strokes roll the burnisher round the end. When finished its shape should be as that illustrated in Fig **121**. Try the staff in the watch frame while polishing the end to check the length. With the lower pivot resting on its endstone, the tip of the upper pivot should be level with the surface of the upper jewel. When standing free in either hole with endstone fitted the staff should lean no more than 7°, as in Fig **122**, which will allow about 0.01 mm to 0.008 mm clearance in the hole.



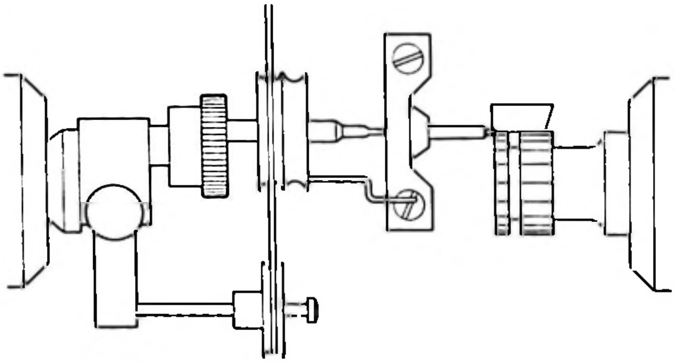
121 Final form of the pivot



122 Gauging the fit of the pivots

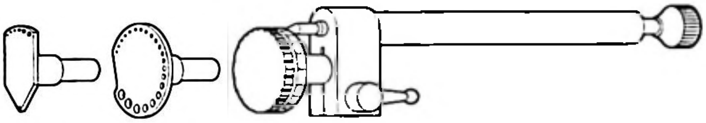
Polishing Attachment for the Lathe

If a Jacot tool is not available a Jacot runner can be made for the tailstock of the lathe with the staff supported in an eccentrically adjustable headstock centre. Fig **123** shows this arrangement with the drive taken from the lathe counter shaft, but a bow can be used equally well. Note the use of the safety pulley to provide a light friction drive to the carrier pulley. This is especially useful when polishing very fine pivots in the lathe where the power of the motor is insensitive to the pressure of the burnisher. A bow will transmit every excess pressure to the hand and is to be preferred for fine work. The safety pulley can be pivoted about the centre to vary the friction of the drive to suit large or small work. Varying sized centres are a taper fit in the nose of the carrier pulley and the whole


123 Motorized drive with safety pulley

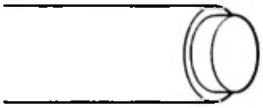
is eccentrically adjustable to raise the work to the level of the Jacot drum.

At one time lathe manufacturers would supply an accessory for polishing clock pivots or large watch pivots. Fig **124** shows the arrangement in which the drum or lantern plate can be revolved in its bracket and positively located by the point passing through the runner.

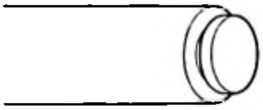


124 Lathe accessory for polishing pivots

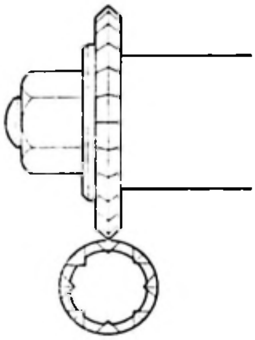
Making a Runner for Watch Pivots
To make a runner suitable for small watch pivots prepare a rod of carbon steel to fit the tailstock. Reduce one end by 1 mm diameter for a length of 2 mm, as in Fig 125. Turn a groove 1 mm deep and 1 mm wide at a distance of 1 mm from the end, as in Fig 126. Fit up the milling spindle on the vertical slide with a 90° cutter, as in Fig 127. Set the cutter so that it just touches the rod. Lower by 0.65 mm multiplied by the diameter of the pivot for which the groove is to be cut. For example for a pivot of 0.12 mm diameter a groove of 0.078 mm in depth is required. Since it is only necessary for the pivot to be approximately half exposed in the groove it can more conveniently be cut to 0.08 mm. Eight grooves to take pivots of diameter 0.1 mm, 0.14 mm, 0.16 mm, 0.18 mm, 0.2 mm, 0.24 mm, 0.30 mm and 0.4 mm will cover all conventional watch pivots. Use the headstock index to space the grooves.



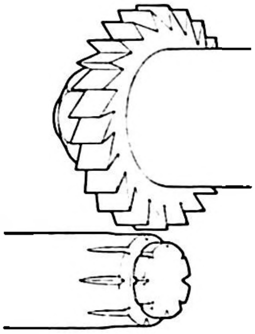
125 Runner for watch pivots, Stage 1



126 Runner for watch pivots, Stage 2

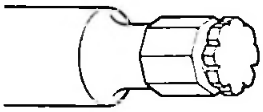


127 Runner for watch pivots, Stage 3



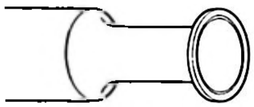
128 Runner for watch pivots, stage 4

Fit a flat-bottomed milling cutter in place of the 90° cutter, reset the milling spindle and again bring the cutter down to touch the grooved flange, as in Fig 128. Starting again behind the first groove raise the cutter by half the diameter of the pivot for which the groove was cut and mill a flat on the rod. Do the same for each groove, raising the cutter appropriately to half the diameter of the pivot for which the groove was cut. Turn away the metal behind the flats to give clearance for the burnisher, as shown in Fig **129**.

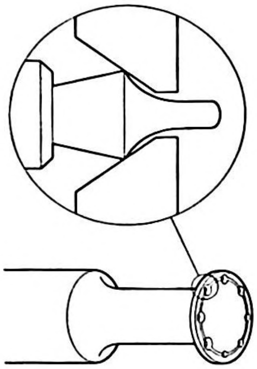


129 Runner for watch pivots, Stage 5

Reverse the rod in the lathe and turn a flange 0.3 mm thick, as in Fig 130, with a shallow 'V' groove on the face 0.5 mm from the edge. Make the clearance for the burnisher behind the flange about 6 mm long to a diameter that will allow 2 mm clearance radially within the diameter of the groove. Index the rod to make eight drilling chamfers in the groove, and drill holes to take pivots of the diameter for which the grooves were cut in the other end of the rod. Chamfer the holes to the form shown in Fig 131 to allow the pivots to enter fully.



130 Runner for watch pivots, Stage 6



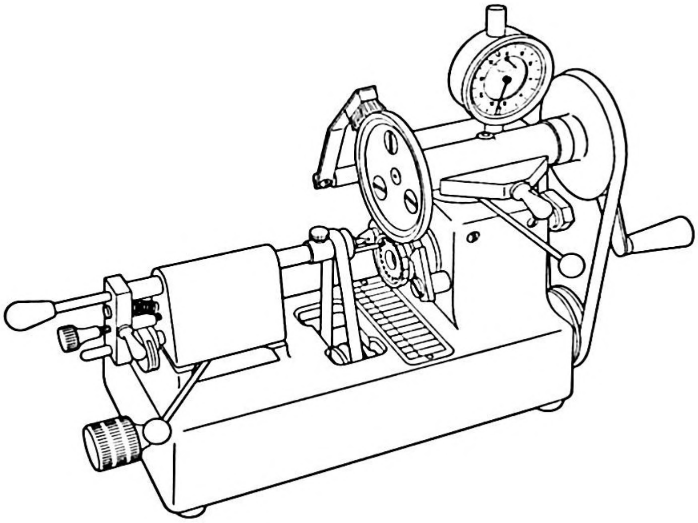
131 Completed runner for pivot ends

Harden both ends of the runner leaving the grooved end dead-hard and temper the lantern end to a pale-blue colour. Polish the holes with diamantine and brass wire filed to a taper. Polish the grooves with diamantine on a wood disc held in the lathe. A guard is not essential but if required can be fitted to the runner and clamped with a screw, as in Fig 118.

Pivot Polishing Tool

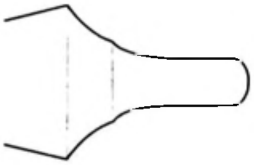
The pivot finishing tool, shown in Fig 132, offers the greatest facility in reducing and polishing pivots. In common with the methods earlier described it uses a stationary safety centre to support one end of the staff while the pivot to be polished is supported in a Jacot drum. The staff is revolved by a belt drive from the pulley of the tungsten carbide burnishing wheel which is turned by a cranked handle. The height of the wheel is determined by a micrometer screw used in conjunction with a dial gauge. The pivots are polished by the edge of the wheel, and the shoulders of train pivots by the face of the wheel, kept in contact by a spring urging the stationary centre towards an adjustable stop screw.

The burnishing wheel is gradually lowered while turning until the pivot is to the required diameter. Once the correct height is found any number of pivots can be polished to the same size without further adjustment. Train pivots can be considerably reduced in size without loss of truth or parallelism provided that the stationary centre is lowered to suit the reduction in pivot size. If this is neglected the pivot will become tapered towards the arbor.



132 Hand operated machine for reducing and polishing pivots

Balance-staff pivots need to be reduced almost to size and the curve polished before final burnishing of the parallel portion in the machine. If this is not done the pivot will take the form shown in Fig 133. There is, however, no practical disadvantage in this and the only objection to it, if it can be called an objection, is that it is unconventional.

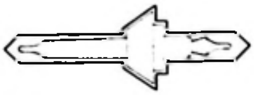


133 Form of reduced pivot.

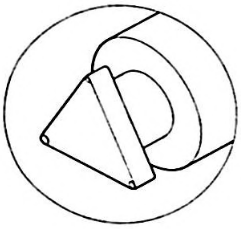
A well-polished pivot will show no marks or scores on its surface. The end of the pivot also, especially of a balance staff, should be quite smooth and free of pitting. With the exception of the polishing tool just described, some practice is necessary to achieve the desired result. It is essential always to keep the pivots copiously lubricated during burnishing to wash away the metal particles and prevent scoring. The ultimate test of a balance pivot is its performance in the watch. It should be quite silent while the balance is oscillating. Any noise of rubbing or rumbling means that the surfaces are not smooth even though they may appear to be so under an eyeglass. Noise means wear, and wear inevitably causes change of rate in the watch. Only the most diligent attention to the finish of the pivots can prevent this.

Turning in Dead Centres

The staff made in the lathe by the method described is not sufficiently precise for use in a precision timekeeper and greater accuracy can be achieved by turning the staff in fixed centres. The work may be done in the lathe or the turns but the principle of rotating the work on its own centre points is the same. For the lathe the drive can be by bow or by motor-driven pulley with a pin to turn the work. For the turns a bow is used with a pulley or ferrule fitted to the work. Whichever method is used the work can be reduced by turning a rough staff in the lathe and finishing it between centres. Fig **134** shows suitable proportions for a rough staff with the finished dimensions superimposed.



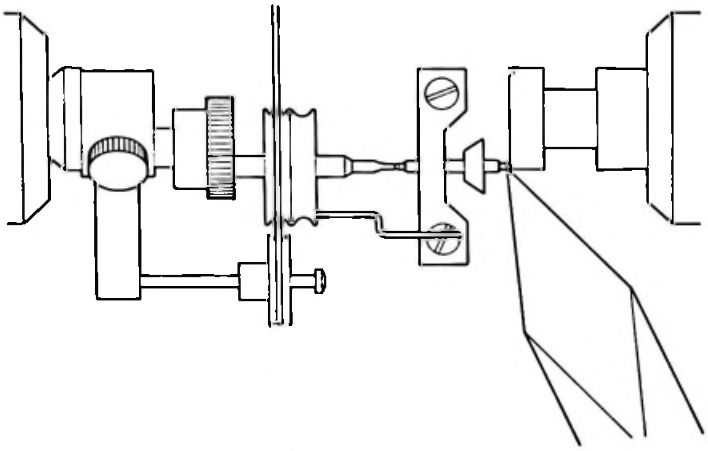
134 Form of rough staff



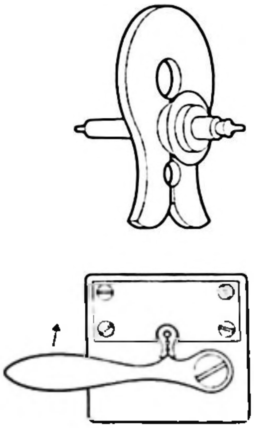
135a Tailstock centres

The Lathe

Fig 135 shows the arrangement for centre turning in the lathe. The work is supported at the headstock in the eccentric safety centre, and at the tailstock in an offset plate with three small chamfered centres, as in Fig **135a**. The offset is simply to bring the work to the edge of the centre plate and to enable the graver to get close to the work. Use the largest chamfer in the plate for the initial turning and polishing. The two centres are aligned by adjusting the eccentric headstock centre. The carrier is a two-piece brass clamp secured by two clamping screws.



135 Turning between centres in the lathe



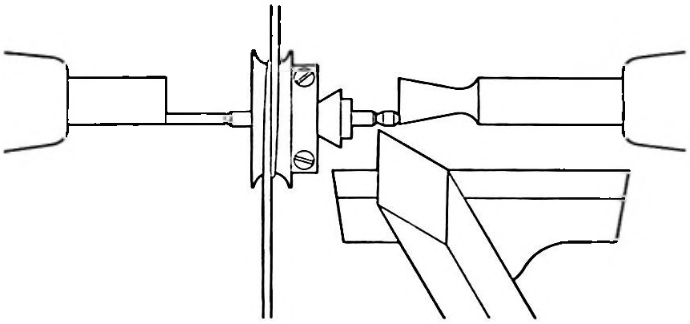
136 Carrier for centre turning

A simple and very effective carrier is shown in Fig 136. The carrier is placed in the tool and sprung open with the lever. Put the arbor into the appropriate hole in the carrier and release the lever and the carrier is ready for use.

The Turns

The arrangement for the turns is shown in Fig 137. The left-hand runner has an eccentric centre to align with the chosen, chamfered centre at the edge of the right-hand runner. The carrier, used in the lathe, is replaced with a ferrule with an adjustable clamp to secure it to the arbor. The threaded half of the clamp is fixed to the ferrule and the loose piece is clamped by two screws. The ferrule will run true only for one size of arbor and eccentrically for all larger or smaller sizes. It is useful to have several sizes to avoid excessive eccentricity. Adjust the staff to turn easily in the centres without freedom and apply oil to the points of the staff.

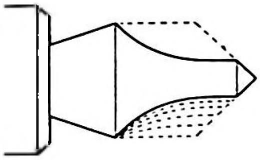
To reduce the cutting pressures and avoid accidental damage to the points the graver should be used inverted as shown. Use the edge behind the point to avoid grooving the surface and rock the graver on the 'T' rest to distribute the cutting along the edge. Obviously the work can be done faster in the lathe because of the constant direction of rotation and the higher speeds available.



137 Turning between centres in the turns

Beware, however, of excessive speed for this will cause wear to the points and the staff may jump out of the centres.

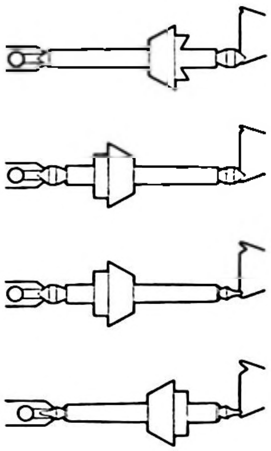
First turn and polish the hub of the balance seat. Next turn on the balance and make the rivet to length. Turn and polish the arbor for the collet and the pivot shoulder. Fit the carrier to the collet arbor and turn and polish the roller arbor and lower pivot shoulder. To turn the pivots select the smallest centre in the right-hand runner to bring the staff close to the edge of the runner. This will give freedom to the edge of the graver to allow sufficient reduction of the pivot before polishing. It is important that the pivot is reduced almost to the size of the jewel hole. If it is left too large because the chamfer is not close enough to the edge of the runner the process of reduction with oilstone paste at the polishing stage will be prolonged and may make the pivot oval or lead to accidental damage.



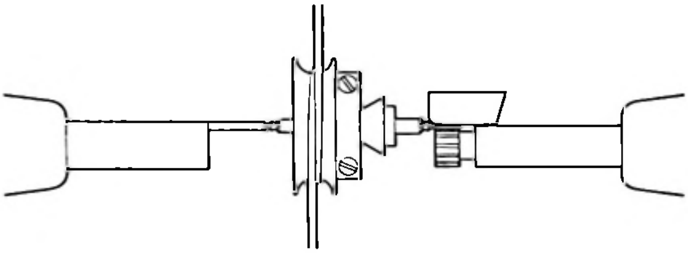
138 Shaping the pivots by gradual reduction

Use a well-sharpened graver with a rounded tip for turning the pivots. Start at the lowest part of the cone and remove the bulk of the unwanted metal before beginning the final reduction of the pivot. In Fig 138 the dashed lines indicate the manner in which the curve should be formed before starting the final reduction. When completed reverse the staff and turn the upper pivot. The finished pivot will be protected by the safety centre. The four stages of turning are shown in Fig 139.

It remains only to polish the pivots. This is done in a bed similar to that used in the Jacot tool but the smoothing and polishing are done with oilstone powder and diamantine. Turn the eccentric left-hand centre to the highest position and substitute the bed runner for the right-hand centre runner, as in Fig 140. The polishing is done with a round-edged polisher as before but as the pivot is beneath, the progress of the work cannot be seen without lifting the polisher. Concentrate the action of the polisher on the curve of the pivot with a light sideways bias, while keeping it in flat contact with the pivot. Shape and polish the ends in the lantern runner and finish the polishing in the Jacot tool or the pivot polishing machine as described. If these tools are not available the burnishing can be done on the bed runner, but this must be thoroughly cleaned of polishing medium that would otherwise be carried round in the oil from the burnisher to cause scratches.

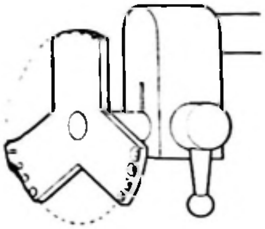


139 Four stages of turning a staff between centres



140 Pivot polishing in the turns

It is not necessary for the staff to be wholly turned between centres. If the upper half is completely turned and polished it can, after parting off, be transferred to the turns for the lower half to be finished. The accuracy will be the same as if it had been turned wholly between centres, but much time will be saved by the use of the lathe.



141 Tailstock accessory for centre turning

Fig **141** shows a useful accessory that can be made to fulfil all the centring requirements of the right-hand runner. The edge of one arm has bed grooves for polishing and reducing, the respective faces of the other two have centring chamfers for turning, and lantern holes for end polishing. Fitted into a bracket with a clamping screw the flange can be set quickly to the required function in lathe or turns without having to change runners.

Fitting the Staff to the Balance

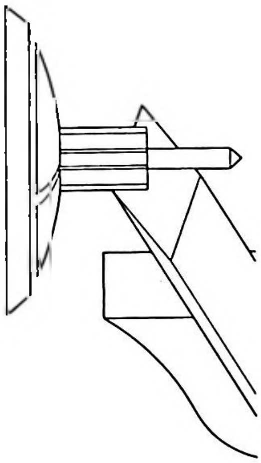
Use the staking tool to rivet the staff to the balance. Open the rim of the rivet with the spreading punch. Four firm blows with a light hammer will be sufficient. Turn the balance and staff through 90° for each blow of the hammer to ensure an even riveting. Finish the rivet with the fastening punch while rotating the balance as before.

Turning and Fitting Pinions

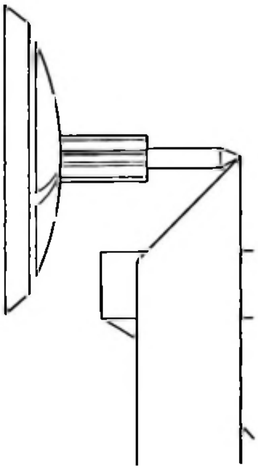
Truing the Centres

Pinions of all sizes can be turned in the lathe with the pinion leaves gripped in a collet. The comments made earlier concerning the maximum possible eccentricity that can occur when using collets are, of course, equally applicable. Where absolute truth is essential, the work should be done between centres. There are, however, many occasions when the ease and speed of turning with a collet can be used to advantage because the possible eccentricity is small enough to be ignored. Even so, discretion must be used if the errors are not to accumulate and render the work unsatisfactory. If, for example, the collet error amounted to 0.005 mm and, after turning the seat for the wheel, the pinion was disturbed before completing the pivot the error of the seat relative to the pivot could rise to 0.01 mm. This could be avoided by completing the maximum possible amount of work before the pinion is disturbed or by turning between centres, as described later.

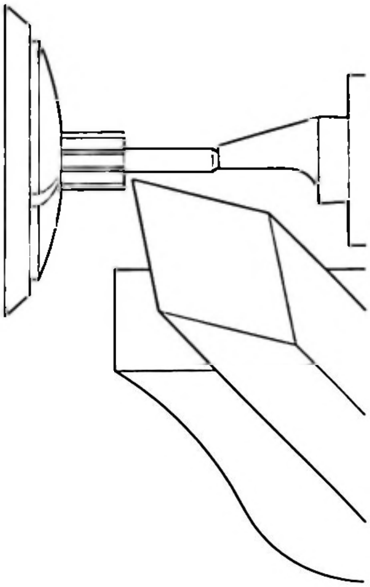
Check first that the arbors and points of the pinion are true with the leaves. Grip the end of the leaves in the collet with a light pressure on the drawbar and true the end of the pinion leaves with the flat of the graver, as in Fig 142. The truth of the leaves can be both observed across the flat of the graver and felt through the handle. Tighten the drawbar and again check the truth. Do not apply excessive force to the drawbar. The pinion will be quite secure with the drawbar tightened by firm pressure from thumb and forefinger only. Run the lathe at about 1,500 rpm and true the point of the arbor with the tip of a sharp graver, as in Fig 143. Now support the point in the tailstock centre and turn the arbor true and parallel, as in Fig 144. Reverse the pinion and true the other end. The pinion may now be turned in a collet or between fixed centres in the lathe or turns. The maximum error of eccentricity of the leaves will be half the maximum possible error of the lathe which will not be visible with an eyeglass. For most practical purposes in watchwork it may be accepted that if no error is visible then none worth while considering exists.



142 Truing the ends of the leaves



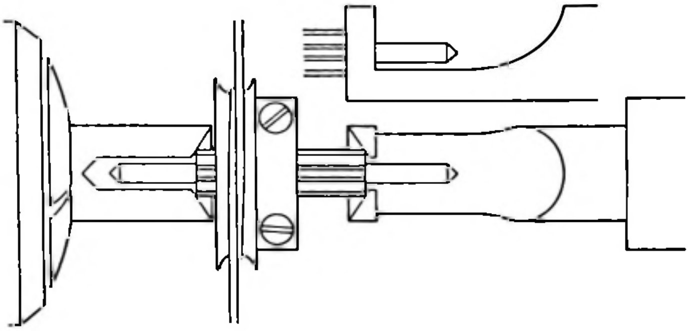
143 Truing the point of the arbor



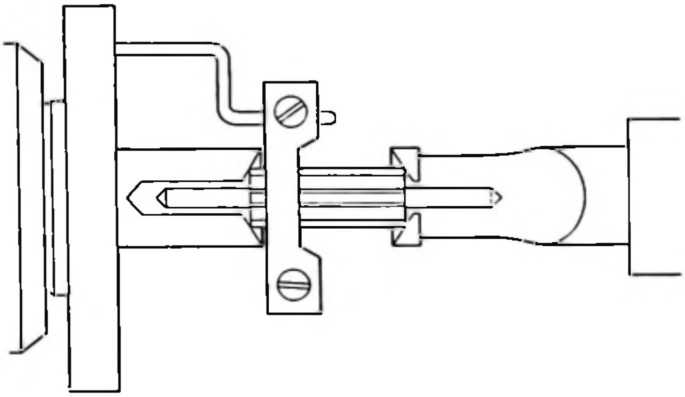
144 Turning the arbor concentric with the point

If absolute concentricity is essential this can be achieved by running the pinion leaves in hollow cones while turning the ends. Fig 145 shows the arrangement. The headstock is locked with a cone in the collet and the tailstock cone formed in a runner with clearance for the graver. If the tailstock runner is sprung against the end of the leaves it will automatically take up deformation at the corners and prevent the point vibrating under the graver. If it is not sprung, reset it close to the leaves when the point is nearly completed and make a final, finishing cut. The friction from contact with the cones will make the pinion stiff to turn and the arrangement shown in Fig 146, with the driving cone trued *in situ*, will relieve the pinion faces of the pull of the driving cord. Prepared in this way the pinion will have no errors of concentricity.

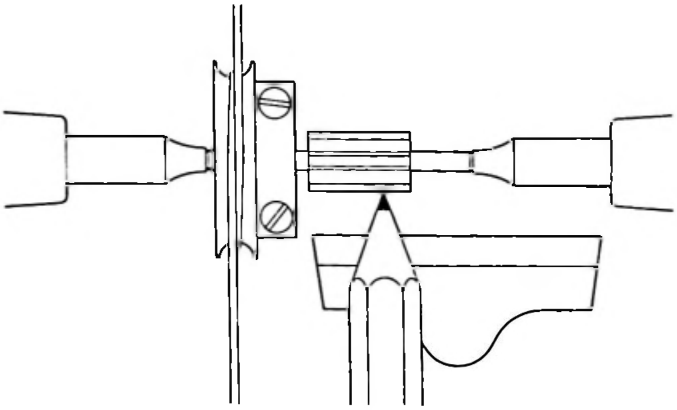
If the pinion is short in the leaves neither of the foregoing methods is suitable for truing the arbors and different means must



145 Turning between cone centres to true the points

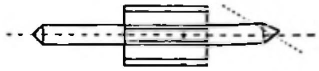


146 Use of the carrier with cone centres

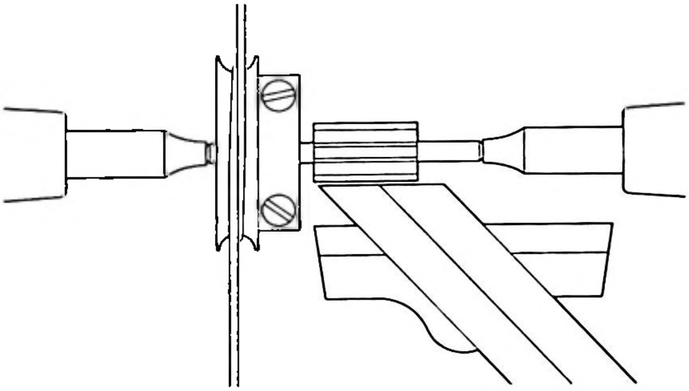


147 Locating errors in short pinions

be used. Put a ferrule on the longest arbor and fit the pinion between centres, as in Fig 147. The turns are most convenient for this. Rotate with a bow and bring the point of a hard lead pencil into contact with the leaves. The highest part of the pinion will show marks from the pencil. File the points of the arbors towards the highest point, as in Fig 148, and repeat the process until the pinion leaves run true. Do not be concerned to file the points truly round and conical. It is only necessary that the tips be concentric at this stage. Check the final truth of the leaves by sighting along the flat of the inverted graver as each leaf passes over, as in Fig 149. Finally turn the cones of the points true, fit into larger centres and turn the arbors parallel.



148 Filing the point concentric



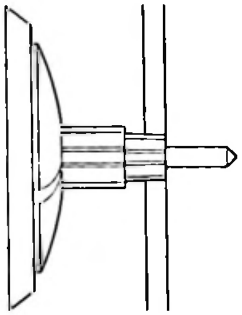
149 Method of sighting errors

Turning the Leaves

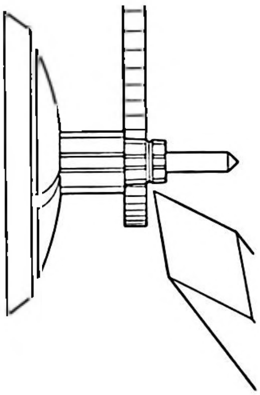
To turn a pinion in the lathe, grip the leaves in a collet and make true with the graver against the corners, as in Fig 142. Remember that the arbor was corrected only within half the possible error of the collet and, if the pinion has been removed from the lathe, it should be re-trued by the leaves to avoid accumulated errors. If the arbors were corrected in the cone runners, the pinions can be trued by the arbor using the tailstock centre. If a wheel is to be riveted to the pinion the seat can be turned with the slide rest set to a 2° taper or an estimated taper turned with the graver. A taper of 0.05 mm in 1 mm will be suitable.

Use the graver inverted when turning the leaves of a pinion. If used flat it will be drawn into the leaves and both pinion and graver will be ruined. To turn pinion leaves in a collet needs more skill with the graver than is required if the work is turned between centres with a cord or bow. If the graver is advanced too quickly it will chatter against the leaves and need frequent sharpening. With a bow or cord the work will stop if the advancement is not sufficiently well controlled.

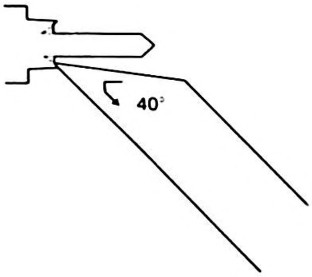
Fit the wheel to a distance from the seat equal to its thickness. This will ensure it is a tight fit on the taper when finally pressed on, as in Fig 150. Turn the rivet to length using the thickness of the wheel as a guide, as in Fig 151.



150 Fitting the wheel seat



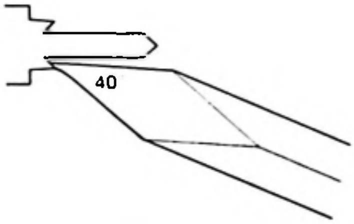
151 Turning the rivet to length



152 Undercutting the rivet

Turning the Shoulders

Turn the shoulder for the pivot and allow the point to undercut the rivet. Start the undercut within the radius of the roots of the leaves with the graver flat on the 'T' rest, as in Fig 152. Gradually deepen the cut until the root diameter of the leaves is reached. Keep the point of the graver always supported against the solid core of the pinion. Rock the graver continually, as indicated by the arrow, to widen the hollow until it is a continuous taper from its root to the tip of the rivet. In opening the diameter of the hollow the long edge of the graver is used. This is not strictly a cutting edge but, if the graver is rocked to provide the clearance below the edge, it will cut rapidly and leave a clean, bright finish.

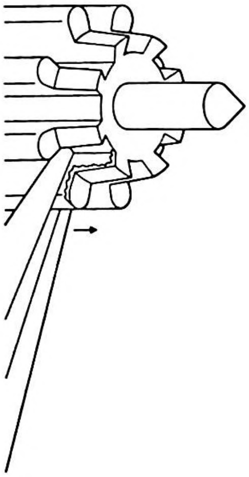


153 Undercutting with inverted graver

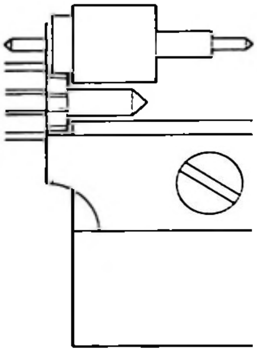
The hollow can equally well be cut with the graver inverted, as in Fig 153, to avoid any risk of breaking the point of the graver by contact with the leaves. There is no special merit to either method. A graver used flat will cut faster than an inverted graver, but needs greater control if risk of accident is to be avoided. Use whichever method achieves the desired result with least expenditure of time. The depth of the undercut will depend on the angle of the graver, which can be changed to suit the fancy of the individual. It was a matter of some pride to English makers to turn the hollow, especially of centre wheels, unnecessarily deep, presumably to demonstrate their prowess with the graver. Some of them took this to extremes by reducing the root diameter of the arbor to increase the effect of depth. This is well enough when a fusee is used to cushion the pinion from the effects of a broken spring, but is courting disaster if a going barrel is used. If the flat of the graver is ground to about 40° it will be suitable for all general work and for turning hollows to a far greater depth than is necessary for riveting.

Turning the Pivot

Before turning the pivot remove the burrs from the roots of the leaves with a pair of sharp tweezers. Grip each leaf gently in the tweezers and slide them along and over the end of the leaf, as in Fig **154**. Measure the length of the pivot shoulder from the seat and turn and polish the pivot. Measure this with a depth gauge or preferably with a dummy pinion, as in Fig 155. The pivot will now be concentric with the wheel seat and within 0.005 mm of the pinion leaves.



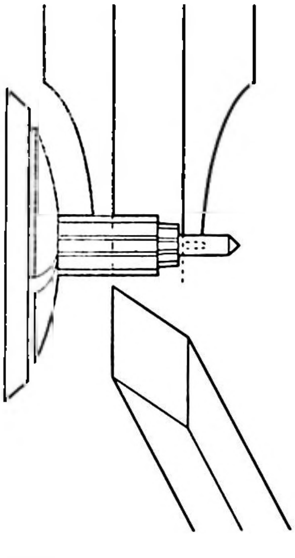
154 Removing the burrs



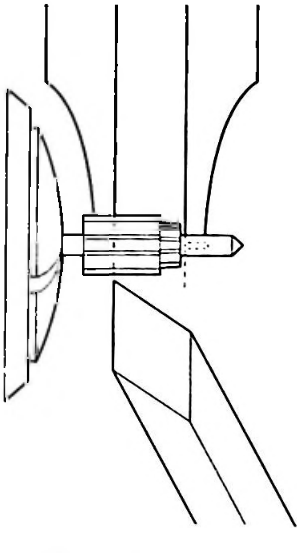
155 Gauging the length of the pivot shoulder

Shortening the Leaves

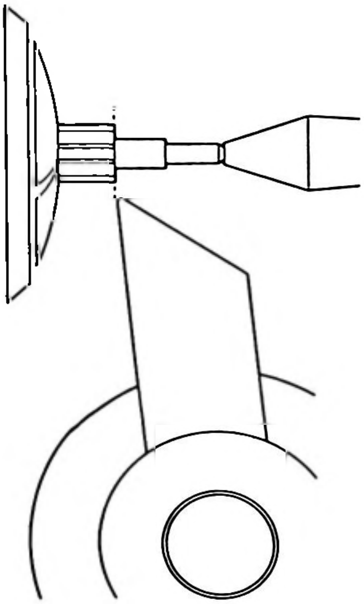
If there is sufficient length exposed, the total required length can be marked prior to turning the pinion end for end, as in Fig. **156**. Mark the tips of the leaves with the graver. If necessary change the collet and hold the pinion by the arbor to mark the length, as in Fig 157. Again, grip the reversed pinion lightly by the leaves and centre the point with the tailstock centre. Tighten the drawbar and check the truth with the flat of the graver.



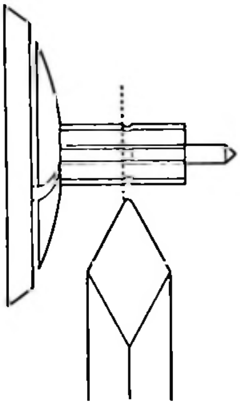
156 Marking the length of the leaves



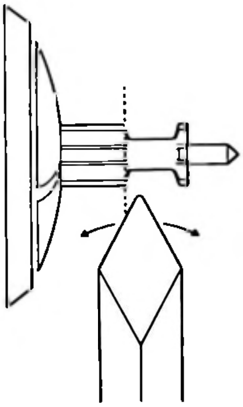
157 Marking the length of the leaves



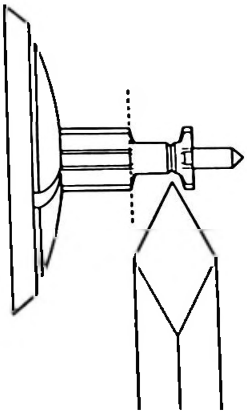
158 Turning the leaves to length



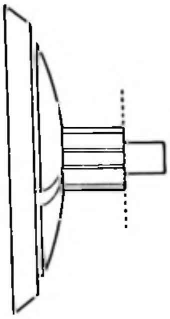
159 Turning the leaves to length with a graver



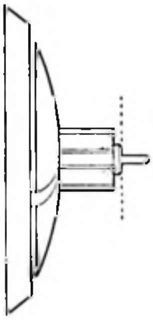
160 Gradually reduce the unwanted leaves to the root diameter



161 Part off the surplus length



162 Face the leaves to final length



163 Turn the pivot and shoulder

If a slide rest is used it is a simple matter to turn away the unwanted part of the leaves and shorten them to form the pivot shoulder. Use a cutter with a small radius to strengthen the tip. Set the edge of the cutter level with the length mark. Turn away the leaves up to the mark and to a diameter below the root diameter of the leaves, as in Fig 158. This face will now be to the length of the pivot shoulder.

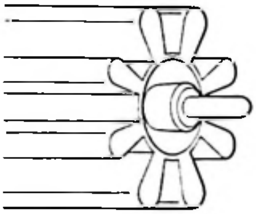
If the work is done with a graver, radius the point to preserve the cutting tip and make a groove level with the length mark, as in Fig 159. Advance the graver steadily as it is rocked sideways to give cutting clearance, as in Fig 160. Do not turn away the guide edge of the groove which indicates the length to the pivot shoulder. When the root of the leaves is reached, part off the end with a pointed graver, as in Fig 161. Face the leaves up to the edge of the groove to determine the length of the pivot shoulder at a diameter below the leaf roots, as in Fig 162. Shorten the leaves to give running clearance and undercut to form the pivot shoulder. Finally turn and polish the pivot, as in Fig 163.

Undercutting the leaves is useful to prevent oil reaching the face of the pinion, especially when this is close to the jewel hole. It also helps to keep the face flat during polishing. For square-bottomed leaves stop the undercut just below the root diameter, as in Fig 164, to leave a thin continuous circle. This circle will broaden slightly during polishing. Round-bottomed leaves can be treated in the same way, as in Fig 165, or opened further, as in Fig 166, when they present a more precise appearance and will polish more quickly.

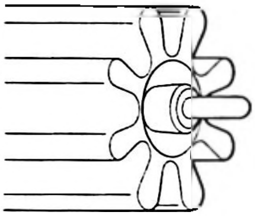
Remove the burrs from the edges of the leaves as described earlier. This is especially necessary with round-bottomed leaves that have been finished, as in Fig 166, where the root of the leaf cannot be reached with the polisher.

Turning Between Centres

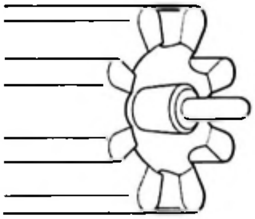
To turn the pinion between centres in the lathe, fit up as shown in Fig 167. The work can be done with the slide rest or the graver. It is quicker to turn and face the leaves with the slide rest, and the arbors and pivots with the graver. The arrangement for the turns is shown in Fig 168, where the work will be done with the graver. Turning between centres offers greater flexibility than turning with a collet. The work can be removed for measurement or examination without accumulating errors and if the arbors are trued, as in Fig 145, the



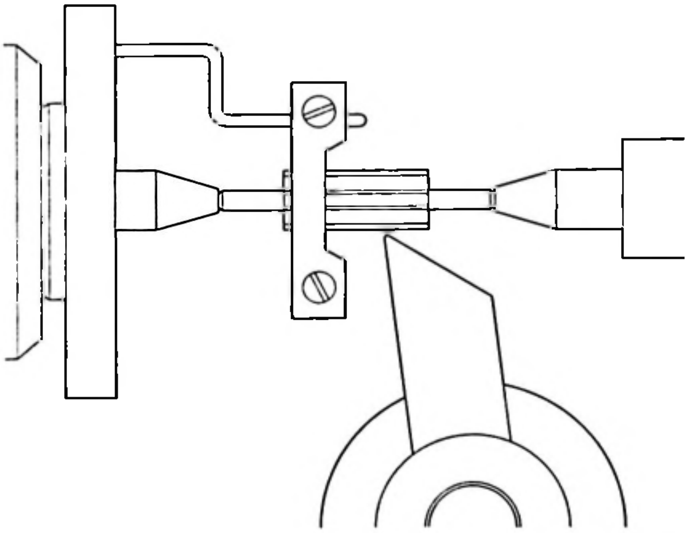
164 Undercut for square-bottomed leaves



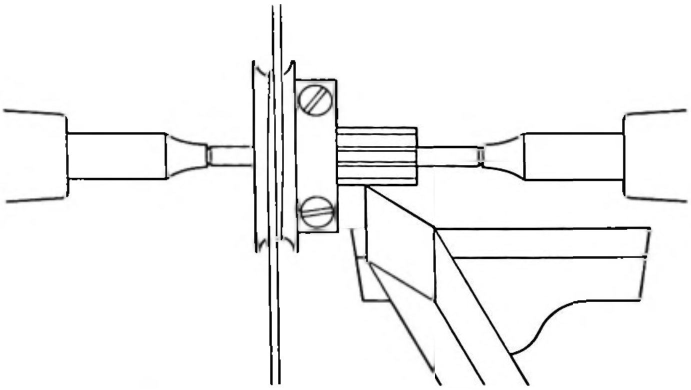
165 Undercut for round-bottomed leaves



166 Alternative undercut for round-bottomed leaves

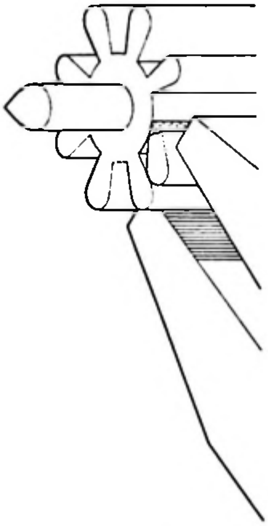


167 Turning between centres in the lathe



168 Turning between centres in the turns

work can be completed without error. Fig 169 illustrates the four principal stages of progress. Note that cumulative errors in the height of the wheel seat are avoided by taking the height of the pivot shoulder from the dummy pinion, and the overall length from the pivot shoulder. On completion of stage 3 the wheel may be riveted on and used instead of the carrier, but this could cause inconvenience in measuring the height of the pivot shoulder. If this measurement is critical it is safer to continue with the carrier and fit the wheel when the turning is completed.

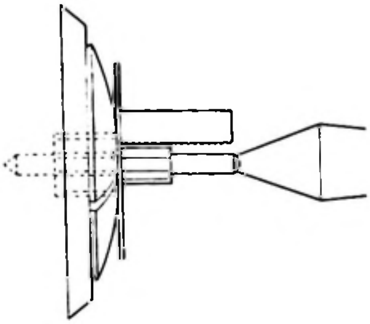


170 Removing unwanted lengths of leaves

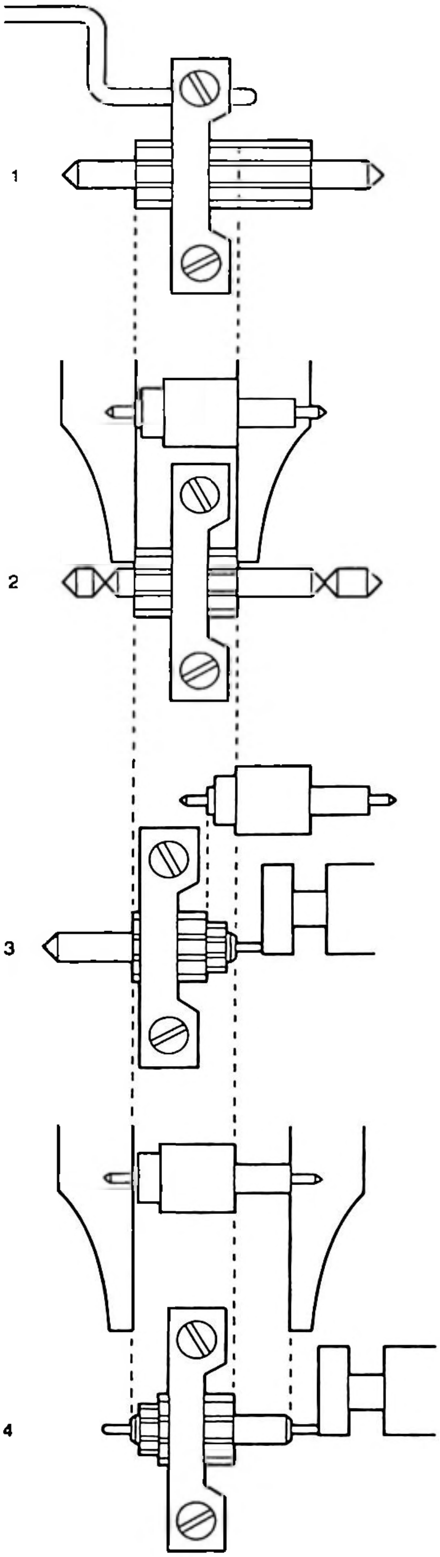
Alternative Preparation

Much time will be saved when centre turning if the component is brought roughly to dimension in the lathe, but the arbors should not be shortened or the truth of the points will be lost.

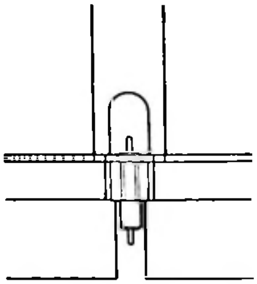
When the turns were in common use it was the practice to shorten the leaves, especially of a centre pinion with a long arbor, by turning a groove and breaking off the unwanted leaves. This can be done with pliers or cutters, as in Fig 170. The leaves cannot be relied upon to break off consecutively and at least the last one will remain. This can be removed with a file and the arbor smoothed ready for turning. The leaves can be shortened by filing while revolving in the lathe, as in Fig 171. Note the washer to protect the collet face.



171 Reducing the length by filing



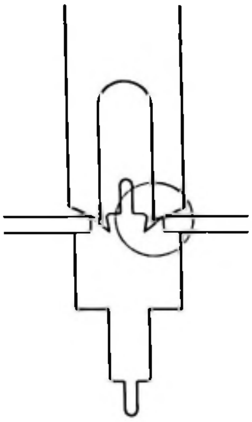
169 Four stages of turning a pinion between centres



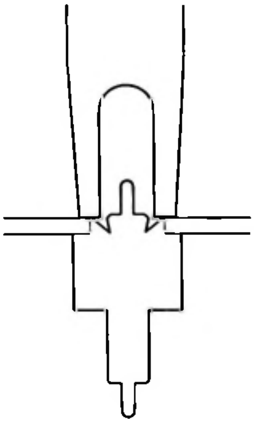
172 Pressing on the wheel

Fitting the Wheel

Complete the pinion by riveting on the wheel which will act as a carrier when polishing the pinion faces. The rivet was turned to enter half-way into the wheel and is, therefore, simply located. Tap the wheel down to the seat in the staking tool with a punch that will pass over the rivet, as in Fig 172. Open the rivet with the spreading punch and finally fasten it with the flat punch, as in Figs 173 and 174. The riveting should be done lightly to avoid distorting the wheel.

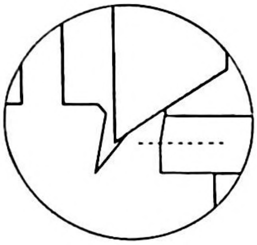


173 Spreading the rivet



174 Fastening the rivet

When correctly fitted the taper of the rivet will form splines in the wheel to take the drive. The rivet will assist in this but is primarily intended to hold the two components together and so does not need to be pronounced. As a guide to the progress of the spreading, examine the rivet after four light blows with the hammer with the assembly turned through 90° for each blow. The rivet will show spreading marks from the punch. These should extend down the rivet for half the thickness of the wheel, as in Fig 175. In this condition there is no danger of distorting the wheel and the leaves will break before sufficient force can be exerted to strip the spline and rivet. Fitted in this way the wheel will run quite true in round and flat.

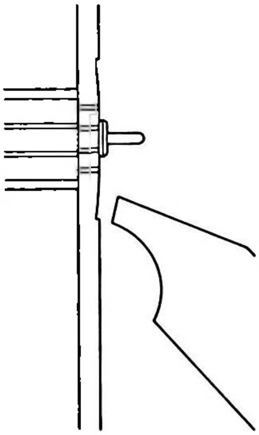


175 Required depth of riveting

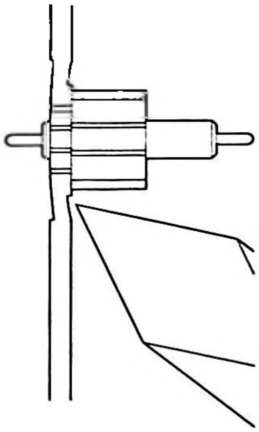
Polishing the Pinion Faces

Relieve the face of the wheel hub to give freedom to the facing polisher, as in Fig 176, and clear away the hub on the pinion side to prevent the wheel finishing compound coming into contact with the pinion leaves, as in Fig 177. The assembly is now ready for polishing the wheel, facing the pinion leaves and burnishing the pivots.

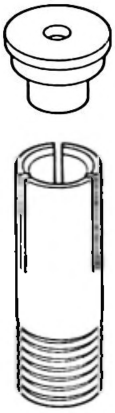
The faces of the pinion leaves are polished with diamantine on bell metal or zinc pads after smoothing with oilstone paste applied with steel or iron pads. A convenient holder for the pads can be made from a discarded collet shank, as in Fig 178. Draw the temper



176 Relieving the face of the hub up to the rivet

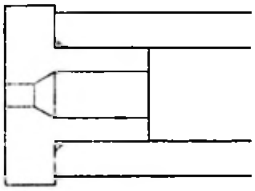


177 Relieving the face of the hub up to the leaves

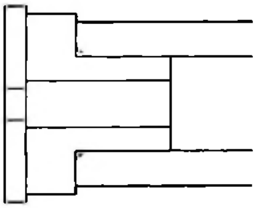


178 Holder with detachable polishing pads

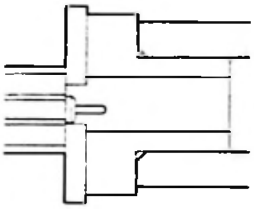
of the collet to a dull-grey colour and remove the cone. Turn the face square and make a chamfer to assist the entry of the pad, which will be held by spring friction from the slotted shank. The pads, illustrated in Fig 179, are turned in the lathe and drilled from the back to make clearance for the pinion arbor. The hole in the face is drilled to a diameter to suit the size of the pinion to be polished. Zinc-faced pads can be made by soldering zinc sheet to brass pads drilled right through, as in Fig 180. Made in this way the faces are easier to dress square and the pad can be used without the holder for polishing in the lathe.



179 Enlarged drilling behind the pad face

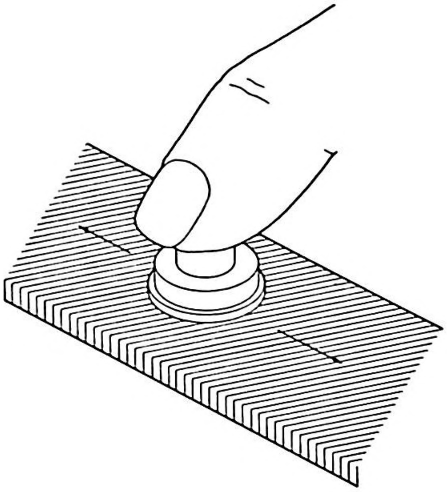


180 Pad faced with zinc



181 Correct clearance of pad-face hole

The size of the hole in the face is not critical but must be related to the size of the pinion to be polished. As a guide to the ideal size the hole should not extend further than two-thirds along the pinion face when working at maximum eccentricity, as in Fig 181. If larger the pressure at the tips of the leaves will be too high and the pinion may tip to score the face of the pad. If too small the pinion face will not be able to wander sufficiently far across the face of the pad and circular scratches may form. Prepare the pads by filing under the finger as shown in Fig 182. A No. 6 pillar file will suit for steel pads and a No. 8 for bell-metal or zinc pads. Always clean the hole after filing to clear away dirt and filing dust.

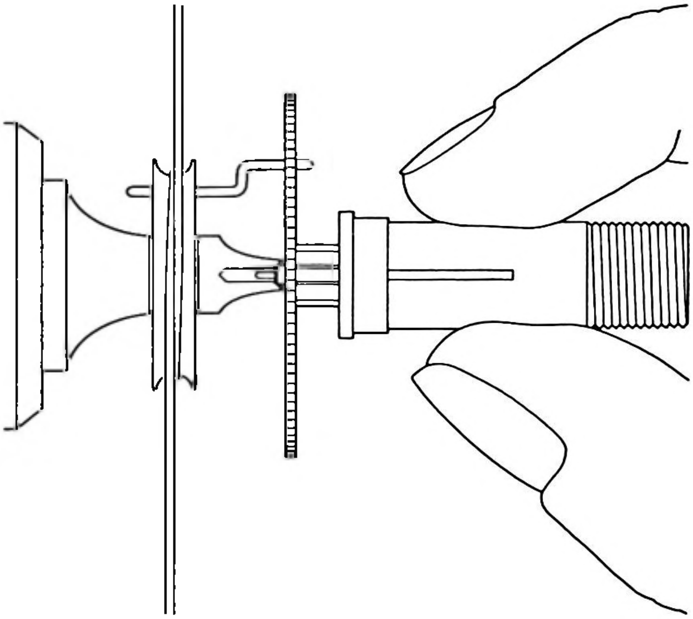


182 Filing the face flat

The polishing can be done most conveniently with a bow, using the wheel as a carrier. Fit up as shown in Fig 183 with a safety centre to guard the pivot. Dab the face of the pad on to the oilstone paste and with a light pressure on the holder, rotate the work with long, steady strokes of the bow. Very little pressure is needed on the pad. Excessive pressure will force the paste into the leaf spaces where it cannot do its work. It will also prevent the pad wandering freely over the pinion face to cause circular scratches and possibly curve the face. Move the bow at about forty-eight single strokes per minute. Faster than this will cause the pinion to rock as the direction of rotation is changed. It is most important that the face of the pinion is not allowed to lose flat contact with the pad. A pinion, turned clean and flat from the cutter, will show a smooth, flat face after thirty to forty seconds' work with the oilstone paste. Thoroughly clean the pinion of all traces of oilstone paste and change the pad for one of bell metal or zinc. Depending on the quality of the diamantine, zinc will sometimes produce the desired finish where bell metal fails.

If zinc is used great care is needed to avoid deforming the soft surface and making the faces of small pinions rounded. Dab the face on the diamantine and use the same technique as for the oilstone paste. The work should again be completed in thirty to forty seconds. The final finish should be scratch-free and quite flat so that when tipped away from the light the surface appears black.

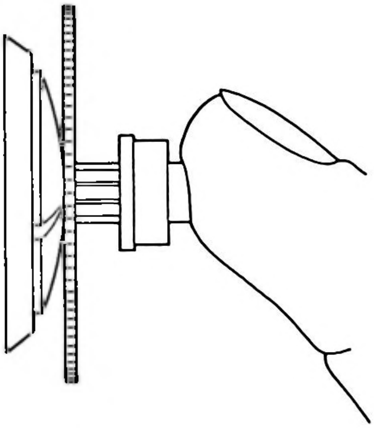
Polishing pinions can cause beginners a good deal of trouble but the fault almost always lies in bad preparation. The first requisite is that the face is turned flat and free from ridges. Any faults will need extra work with the oilstone pad and this may cause the surface to become rounded. As a consequence the diamantine pad will touch only at the centre and the whole face will not polish. In addition, the circle at the leaf roots will broaden and look coarse. If



183 Polishing by bow and carrier pulley

the work is prolonged and the bow reversed continually at the same part of the stroke, the face is likely to become out-of-square causing the arbor to rest against one side of the hole and form circular scratches. A white crystalline edge to the leaves shows that the diamantine has been rolling between the face and the polisher and was insufficiently crushed during mixing. This fault can also indicate that the pinion is not sufficiently hard. If the surface becomes in any way deformed there is no alternative but to reface the pinion with a cutter. The necessary flat face can be achieved without particular skill if the slide rest is used. To get the same result with a graver requires much more practice in keeping the edge of the graver square with the axis of the pinion. If this vital first preparation is properly done success in polishing with pads will soon follow and this method will be found quite the quickest and least troublesome. Both face and rivet can be polished in this way.

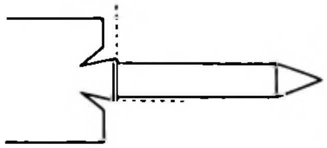
When the pivot shoulders are sufficiently long the polishing can be done equally well in the lathe using the pad only on the tip of the finger, as in Fig **184**. Again use only sufficient pressure to hold the pad in flat contact and at the same time move it gently from side to side to spread the polishing area. This method is not suitable for small pinions when flat contact cannot be assured.



184 Polishing in the lathe

The lapping tool, shown in Fig **411**, can be used for facing pinions and polishing shoulders at the same time. Steel discs are used for the oilstone paste and brass or zinc for diamantine. The spindle is driven by a cord from the lathe motor and can be laterally adjusted against stops and moved axially to contact the work face. Pinions of more than 3 mm diameter can be polished quite quickly with this accessory but for general watch pinions the polishing pads are quicker and more convenient. Skilled work with the polishing pads will complete the work in less time than is required to set up the lapping tool, which is intended more for repetitive work.

When the arbor is to be polished after the facing polish is completed it is necessary, when undercutting the leaves, to form a collar close to the corner to protect the pinion face. This is shown in Fig 185 in which the dashed line above shows the limit of axial movement of the arbor polisher, while the dashed line below shows the limit of radial movement of the facing polisher.



185 Shoulder to protect the pinion face

5

WHEELS AND PINIONS

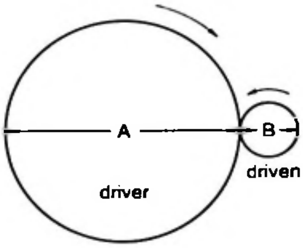
Wheel-Tooth Forms

In watch trains the ratio of the number of turns of the driven wheel to one turn of the driving wheel is always greater. In Fig 186 the larger, driving circle is four times the diameter of the driven circle. One turn of the large circle will cause the small circle to complete four turns. The ratio is 4:1 and is expressed:

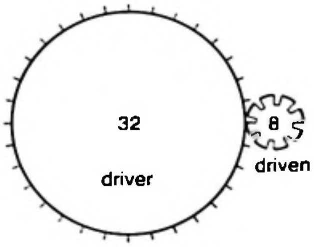
$$\frac{\text{Diameter of driver}}{\text{Diameter of driven}} = 4$$

Smooth rollers cannot transmit power without slipping and even if they could it would be practically impossible to ensure their exact diameters and the ratio would be inaccurate. To prevent the rollers slipping, teeth are added to the driving circle to engage slots cut into the driven circle, as in Fig 187. The wheels can now transmit power without slipping but the basic circles still represent the ratio. This ratio can now be expressed by the numbers of teeth in the two wheels which must be in the same proportion as the diameters of the circles. For a 4:1 ratio the driving wheel needs four times the number of teeth of the driven wheel. If the driver has 32 teeth then the driven requires 8 and the ratio is 4:1, expressed $\frac{32}{8} = 4$ which is the same as the two base circles. If the number of teeth is changed for any reason the ratio of the numbers to the ratio of the diameters of the circles must be strictly maintained.

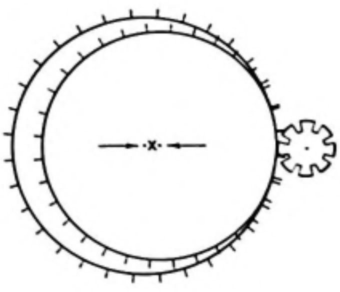
In gears the circles are called pitch circles and they are the foundations upon which all gear trains are designed, see Fig 218. In considering again the ratio of $\frac{32}{8} = 4:1$, if the pitch circles are not in the same ratio then a tooth of the driver, in this case too large in diameter, Fig 188, cannot enter the slot in the driven wheel, for the pitch of the teeth is too great. If the wheel is drawn smaller (inner circle) and to the correct pitch it will be too far from the pinion to engage the slots and must be moved closer by the distance x. The pitch circles then determine not only the velocity ratio but also the pitch centres of the two wheels. See Fig 218 for nomenclature.



186 $\frac{A}{B}$ = Ratio = 4:1



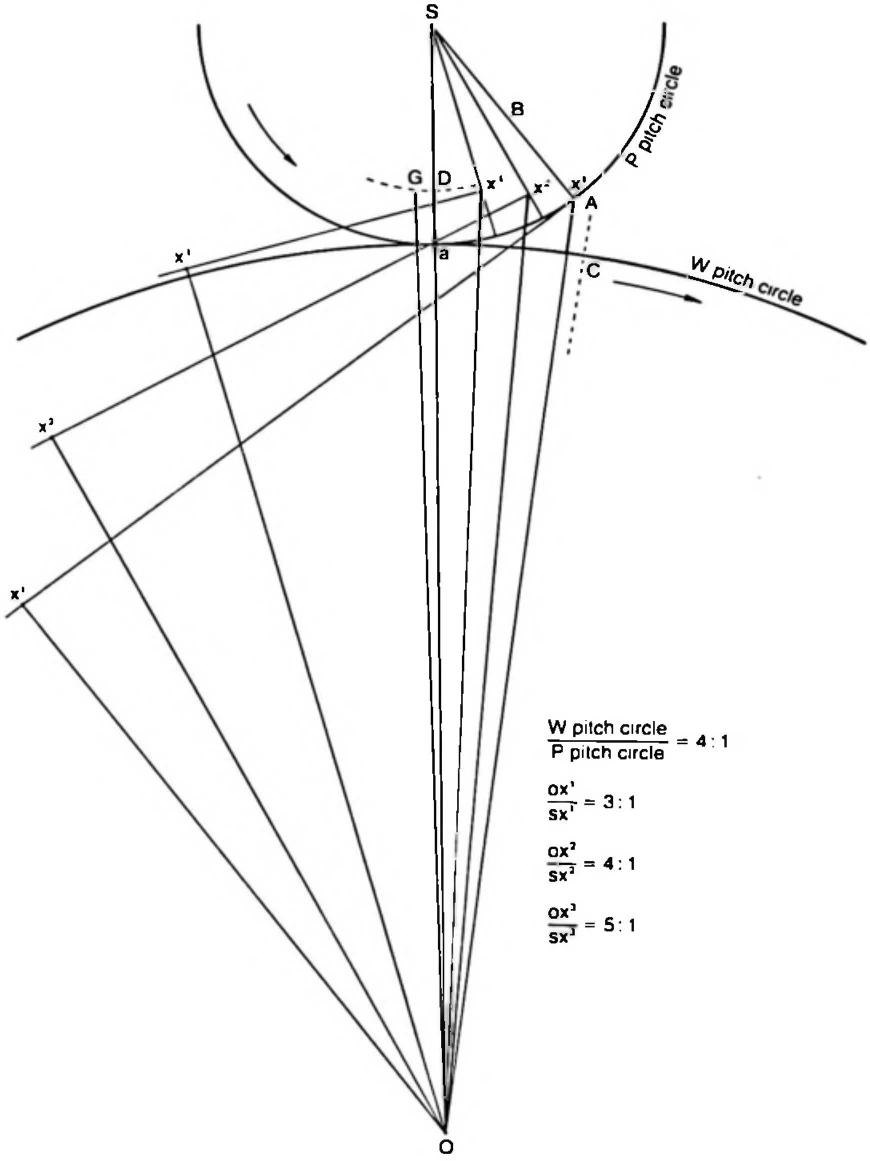
187 $\frac{32}{8}$ = Ratio = 4:1



188 Incorrect velocity ratio

Velocity Ratios

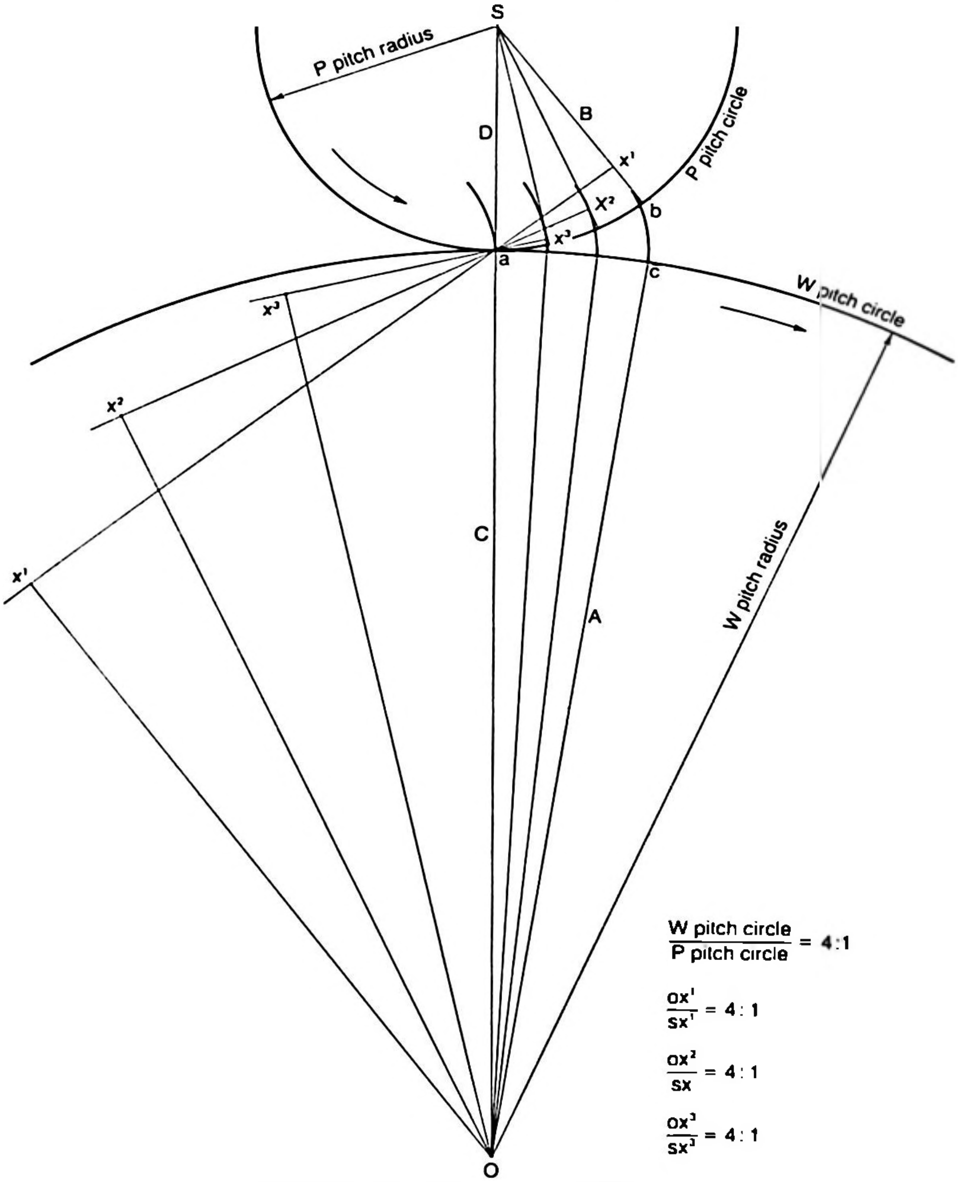
In Fig 189 it can be seen that straight teeth cannot impart motion with constant velocity. Tooth *A* of the wheel has carried leaf *B* of a pinion of 10 to the limit of their intersection. The velocity of the wheel tooth at the moment of engagement at *a* is too low because the pinion radius, at the dashed line on *D*, is too small. The tooth will accelerate to x^1 and depart, allowing the following tooth G to fall through distance *GD* and make arc *ac* equal in length to arc ax^1. Lines x^1, x^2 and x^3 are normal to the pinion face and represent the common line of power transmission. The values of $\frac{ox}{sx}$ show the inconstancy of velocity ratio and consequent inefficiency of power transmission.


S
B
P pitch circle
G
D
x¹
x²
x¹
A
a
C
W pitch circle
x¹
x³
x¹
O
W pitch circle / P pitch circle = 4 : 1
ox¹ / sx¹ = 3 : 1
ox² / sx² = 4 : 1
ox³ / sx³ = 5 : 1

189 Inconstant velocity ratio from straight teeth

In order to equalize the velocity ratio the tip of the driver must be curved. In Fig 190 the tooth *A* is about to leave leaf *B* of the driven pinion and tooth *C* will take up contact with leaf *D*. The curved addendum of the driving tooth *A* has maintained uniform contact with the driven leaf *B* so that the arc *ac* traversed by the driver is equal in length to the arc *ab* traversed by the driven pinion and their velocity ratios are equal.

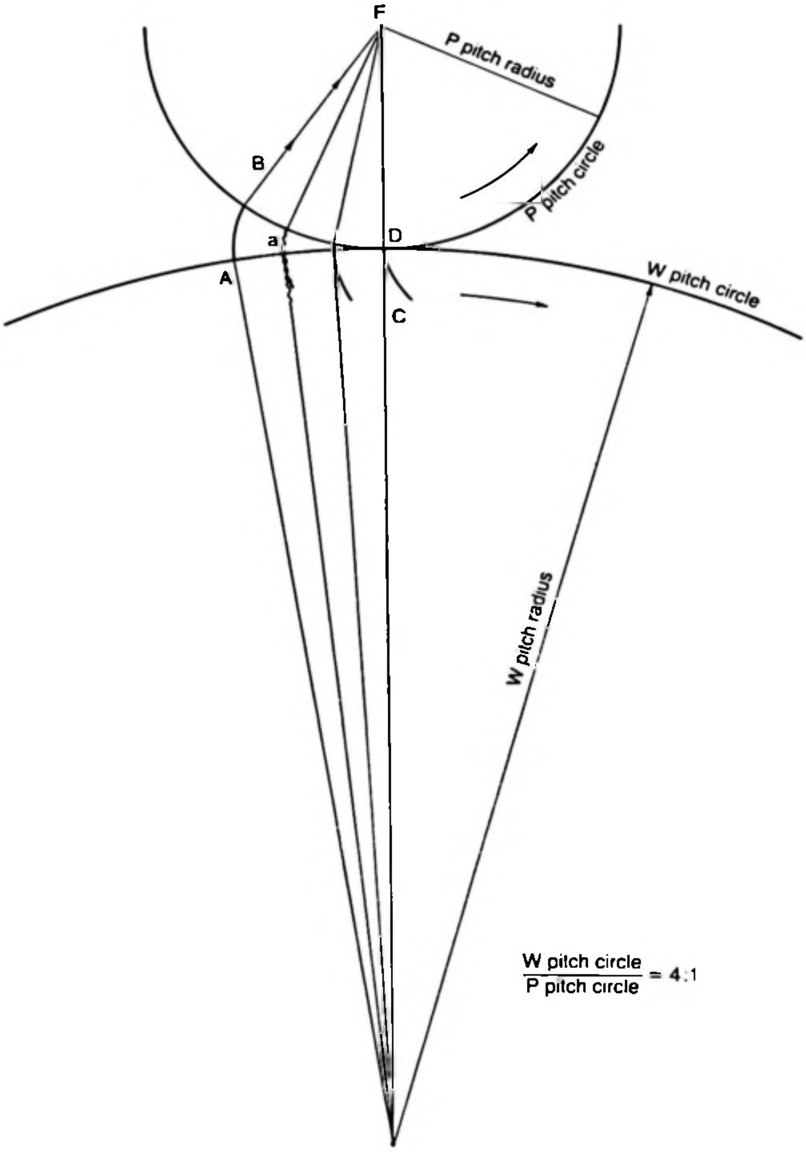
The proof of the equality of the velocity ratios is seen in the values of $\frac{ox}{sx}$. This is the common line of power transmission of the wheel and pinion. When the tooth curve is correct it will pass through the point of contact of the pitch circles to make: $\frac{\text{Effective radius } Ox}{\text{Effective radius } Sx}$ equal to the ratio of pitch diameters at each stage of departure.


S
P pitch radius
D
B
x¹
X²
P pitch circle
b
x³
a
c
W pitch circle
x³
x²
x¹
C
A
W pitch radius
O
W pitch circle / P pitch circle = 4:1
ox¹/sx¹ = 4 : 1
ox²/sx = 4 : 1
ox³/sx³ = 4 : 1

190 Constant velocity ratio from curved driver addendum

Centre Line of Wheel and Pinion

It will be noticed that the whole of the action has taken place after the line of contact of the two pitch circles. This occurs when the driving-wheel teeth carry the addendum. If the condition were reversed so that the driven wheel carried the addendum then the whole of the action between the teeth would occur before the contact line of the pitch circles. This reversal would change the action of the engagement from one of disengaging to engaging and the contact friction would increase. In Fig **191** the smaller, driven wheel carries the addendum. Tooth *A* is about to contact tooth *B* and take up the drive from teeth *C* and *D* while approaching the centre line. The friction arising from the sliding contact will act towards *F* and increase the pressure on the pivot. The surface finish

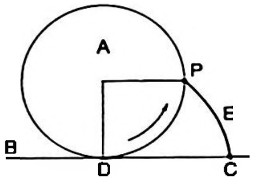


191 Action before centre line when addendum is driven of the contact surfaces can also cause increased pressure as seen at *a*, where irregularities in the surface are exaggerated to illustrate the binding effect of the approaching engagement. If the drive is reversed to a receding action the irregularities will slide over each other without binding. It is particularly important to avoid the effects of approaching contact in watch trains where the ratios are high and the power available is relatively low, especially at the faster moving wheels.

To summarize the above the addendum must be on the teeth of the driver and the curve of the addendum must ensure equal velocity ratio of both driver and driven. Conventionally, when the driven wheel has fewer than 20 teeth it is called a pinion and, because of their form, the teeth are called leaves.

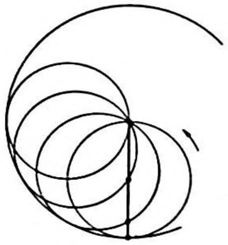
The Cycloidal Curve

The most suitable addendum for watch train wheels is derived from the cycloid curve generated by a point at the edge of a circle rolling along a straight line. This is shown in Fig **192** in which the circle *A* has rolled along line *B* for the distance *CD* and the point *P* has traced the cycloid *E*.



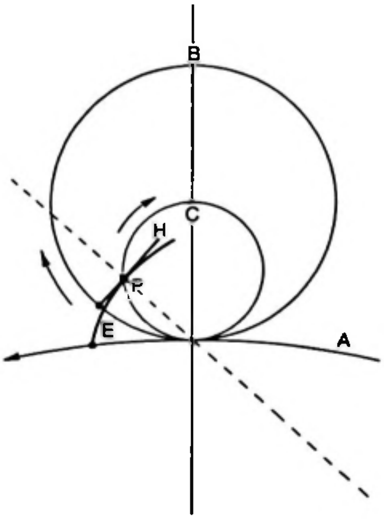
192 Generating the cycloidal curve

In producing the addendum for the driving wheel the generating circle is rolled around the pitch circle of the wheel to produce an epicycloid. The driven pinion has no driving addendum and its leaf flank is generated by rolling the circle around the inside of its pitch circle to produce a hypocycloid. If the generating circle is half the diameter of the pitch circle the hypocycloid curve will be a straight line, as in Fig **193**. This straight-line dedendum is most useful for watch trains with high-ratio gears, for it simplifies the manufacture of the driven member. In a typical ratio of 8:1 the driver, by reason of limited space, may have only 64 teeth and the driven, 8 leaves for a pitch diameter of, say, 0.75 mm or less. It may be imagined that machining a calculated curve to the flank of so small a leaf would be impracticable, but a straight flank is simple to machine.



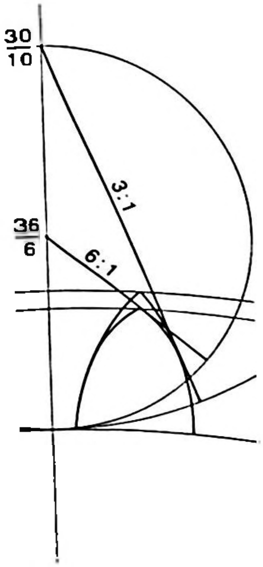
193 Generating the hypocycloidal curve

In Fig **194** the arc *A* and the circle *B* represent the pitch circles of a wheel and pinion. The small circle *C* is the generating circle resting on the outer edge of *A* and the inner edge of *B*. If *A* is turned in the direction of the arrow it will rotate *B* and, within it, *C*. The point *P* in the edge of *C* will trace both the epicycloid *E* and the hypocycloid *H*. At any moment in the generation of the arcs the dashed line through point *P* will represent the line of thrust and will extend through the line of contact of the pitch circles. The curves are repeated on each side of the wheel tooth. The width of the tooth equals the width of the space.

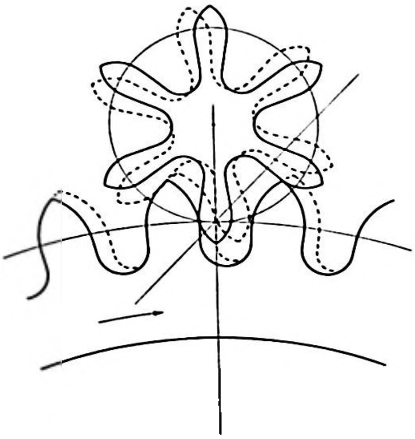


194 Generating the epicycloid and hypocycloid curves with uniform velocity ratio

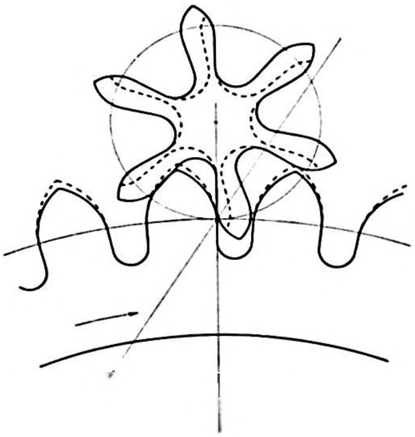
The height and shape of the curve will change with the velocity ratio. In other words it will change with the relative size of the generating circle. Fig **195** illustrates the differences in the curves for a wheel of 30 teeth driving a pinion of 10, and a wheel of 36 teeth driving a pinion of 6. The lower ratio produces the tallest curve and with the pinion of 6 the contact will start before the centre line. This cannot be avoided without widening the teeth, as shown by the dashed line in Fig **196**, to raise the height of the apex of the curve. If the tooth width were increased sufficiently to prevent contact before the centre line the pinion leaf would have little width. This is shown in Fig 197 with the resultant shift in the power transmission closer to the centre of the pinion to cause increased friction at the pivots.



195 Effect of ratio on addendum height



196 Action of 6-leaf pinion



197 Effect of increased addendum to drive pinion of 6 leaves

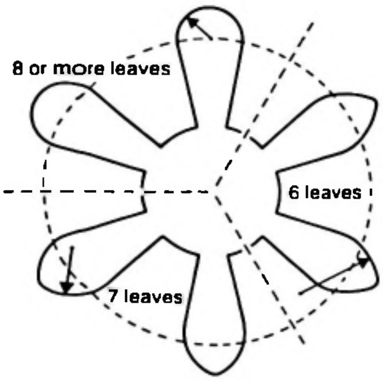
For pinions of 10 and more leaves the curves will ensure that the contact occurs at the centre line and all the lead will be after this point. For pinions of fewer than 10 leaves some contact before the centre line is unavoidable. For a 6-leaf pinion this will amount to 10° before the centre line.

It is sometimes suggested that simply pitching the wheel and pinion closer together will advance the pinion leaf to the centre line to improve the action. This is a fallacy for it will only increase the pressure on the pivots and cause sliding and reduced efficiency.

Pinion Addendum

Although driven pinions do not need a working addendum the tips of the leaves are extended beyond the pitch circle. This is to prevent any catching of the wheel tooth flanks due to errors of cutting or pitching. For pinions of 6 and even 7 leaves the tips sometimes start below the pitch circle, as in Fig 198, to assist the lead before the centre line.

With pinions of 10 leaves and more, all the lead will occur after the centre line and the action will be smoother because the angle of rotation per leaf is smaller.



198 Forms of pinion addendum

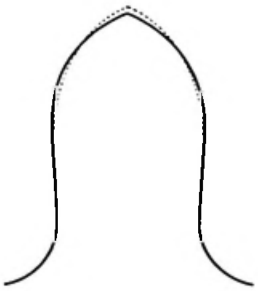
Defects of Application

It might be thought that if the cycloids were perfectly generated and the wheels and pinions perfectly formed then the lead would be quite smooth, irrespective of the numbers of teeth and leaves. Unfortunately, although the curves can be drawn to large scale with great accuracy, it is not possible to reproduce them with proportional accuracy to the very small scale required in watchwork. In addition the freedoms required in the pivots upset the action of the curves, even supposing it were possible to cut a wheel and pinion with perfect circular pitch and mount the two together with perfect concentricity. The errors of pitching arising from these faults cause continuous changes in the action of the teeth with consequent variation in lead and power transmission. If the train is not sufficiently carefully made the phase losses in each pair of gears can coincide to produce a cumulative fall in power transmission that would be unacceptable in a watch. The effects of errors in the gears are greater as the number of leaves in the pinions decreases. For this reason the numbers should be kept as high as possible, especially at the slower-moving end of the train, to prevent cumulative phase losses occurring.

Alternative Addendum Curves

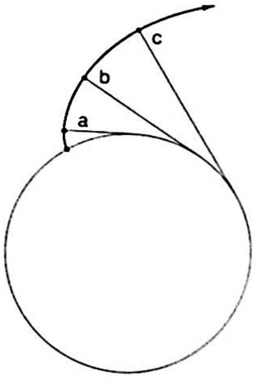
By careful attention to pitch diameters, pinion polishing and 'depthing' of the pairs, the watchmaker can make a smooth running train with smooth power transmission. The production engineer cannot bring such minute attention to bear upon every component and prefers a tooth form that will work acceptably with greater tolerances for increased simplicity of cutter design. The difficulties of the production engineer have led to the introduction of modified curves based on the cycloidal system. The pinions are much the same although circular roots have taken the place of the earlier square roots. These are stronger and so are especially useful where power transmission is high. The principal change is to the tooth forms which are now more generally referred to as 'ogival' in shape. They have been generally adopted by watch and instrument makers with small variations in the curves dependent on the fancy of the maker. The principal schools of origin are the Continental, the American and the British.

The basic difference in shape is illustrated in principle in Fig 199, in which the dashed line is the cycloid and the full line the 'tip-relieved ogive'. The ogive is a slightly fuller curve and shorter in length than the cycloid. The fuller curve has the effect of slowing the rotation of the wheel just as the following pinion leaf approaches the point of contact. By this means the leaf is slightly in advance of the approaching tooth and contact is assured without risk of catching, which would give rise to extra friction in an imperfect depth. This allows a greater tolerance in diameters, concentricity and bearing freedom. The tolerance allows the pitch centres to be further apart than the theoretical pitch circle diameter would indicate, and within the limits imposed by the cutter designer the variation in the depth is not harmful to the action.

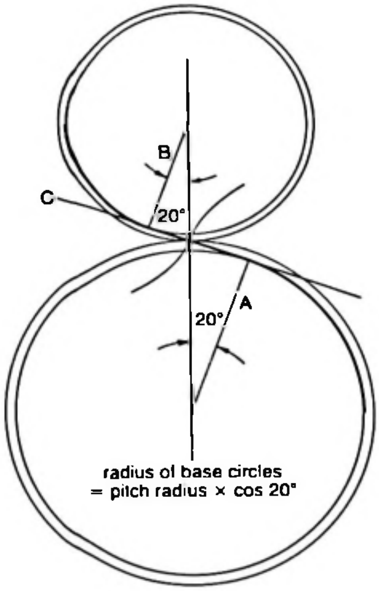

199 Cycloid in dashed curve compared with tip-relieved curve

Involute Teeth

Teeth of involute shape are sometimes used in watches where high tooth pressures occur, such as in winding wheels. The involute curve is traced by the end of a cord when unwound from a cylinder. It is shown in Fig 200 where the tangents *a*, *b* and *c* represent the



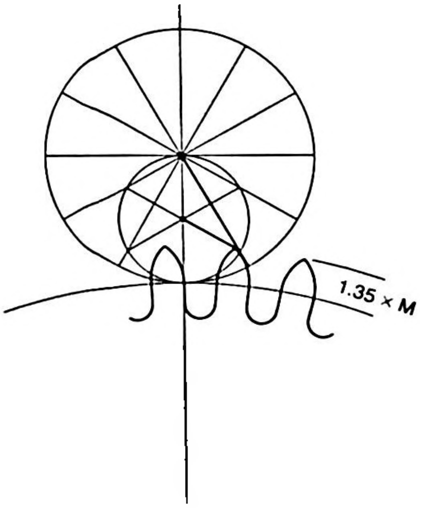
200 Generating the involute curve



201 Principle of involute transmission

pressure angles of their respective contribution to the curve. Because the involute form needs both addendum and dedendum for driver and driven the pitch circle cannot be used to trace the curve. An inner, base circle must be used. The radius of the base circle is derived from the radius of the pitch circle multiplied by the cosine of the pressure angle of the teeth. The pressure angle is the power transmission line common to both wheels.

Fig **201** illustrates the uniform curve of the teeth generated by a common cord unwinding from the base circles. *A* and *B* are the lever radii, or base circle radii, of the respective wheels and C the line of thrust at a chosen 20° to the common tangent. The action occurs equally before and after the centre line and the lead is uniform. Involute teeth are not suitable for the high ratios needed in watch trains. When a great disparity exists between the sizes of driver and driven the pressure angle of the curves of the pinion becomes excessive and causes unacceptable friction and pressure on the pivots.

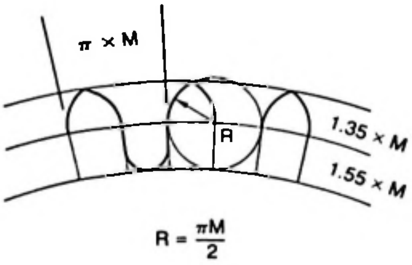


202 Common addendum computed from the module

To Determine the Full Diameter

Although the pitch circles are used to determine the detailed dimensions of wheels and pinions the full diameter is the most useful dimension for their manufacture. The full diameter is the pitch diameter plus twice the addendum. While the pitch diameter for the wheel is simple to determine, the full diameter may be a matter for trial or compromise if the formula for the cutter form is not known.

If the strict theory of cycloid curves is followed exactly then every change in wheel diameter and number of teeth would require a different curve and height of addendum. Fortunately the difference in the curves is small enough to allow the use of standard curves that are easier to produce and allow some duplication of cutters for different wheels. The addendum for such cutters is derived from the module, and for two differently sized wheels having the same module the addendum would be the same by calculation. An example of this is shown in Fig 202 where two wheels of 0.2 mm module drive different pinions in the ratio of 3:1 and 6:1. The constant addendum in both wheels is 1.35 × M, or 2.7 × M for the full diameter. The amount to be added is 0.54 mm but an epicycloidal curve would be taller for the lower ratio. However, less of the tip of the true curve is used as the ratio diminishes and the constant addendum would be acceptable for both wheels. The shape of the curves cannot be correct in both wheels because the lower ratio, being traced by a larger generating circle, should have a shallower curve. The increased curvature will cause the wheel tooth to decelerate up to the peak of the curve and then accelerate to the limit of the lead. The method of generating the constant addendum is shown in Fig 203. The cutters can be bought as a set of six for wheels of 17 to 135 teeth. The lower the cutter number the greater the range of wheels that can be cut, for example cutter No. 2 will cut wheels of 55 to 134 teeth whereas No. 6 will cut wheels of only 17 to 20 teeth. A different set is required for each module.



203 Derivation of common addendum

British Standard 978 Part 2

Gears for Watch and Clock Trains

Table of values of A and R

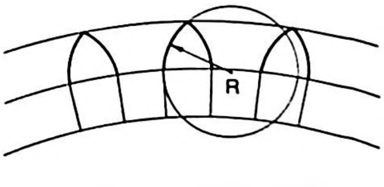
t	*Ratio T/t*	*3*	*4*	*5*	*6*	*6½*	*7*	*7½*	*8*	*8½*	*9*	*9½*	*10*	*11*	*12*
6 Teeth	*A*	1.259	1.280	1.293	1.303	1.307	1.310	1.313	1.315	1.318	1.320	1.321	1.323	1.326	1.328
	R	1.855	1.886	1.906	1.920	1.926	1.930	1.934	1.938	1.942	1.944	1.947	1.949	1.954	1.957
7 Teeth	*A*	1.335	1.359	1.374	1.385	1.389	1.393	1.396	1.399	1.402	1.404	1.406	1.408	1.411	1.414
	R	1.968	2.003	2.025	2.041	2.048	2.053	2.058	2.062	2.066	2.069	2.072	2.075	2.080	2.084
8 Teeth	*A*	1.403	1.430	1.447	1.459	1.464	1.468	1.471	1.475	1.478	1.480	1.482	1.484	1.488	1.491
	R	2.068	2.107	2.132	2.150	2.157	2.163	2.169	2.173	2.177	2.181	2.184	2.187	2.193	2.197
9 Teeth	*A*	1.465	1.494	1.513	1.526	1.531	1.536	1.540	1.543	1.547	1.549	1.552	1.554	1.558	1.561
	R	2.160	2.202	2.230	2.249	2.257	2.263	2.269	2.274	2.279	2.283	2.287	2.290	2.296	2.301
10 Teeth	*A*	1.523	1.554	1.574	1.588	1.594	1.599	1.603	1.607	1.610	1.613	1.616	1.618	1.623	1.626
	R	2.244	2.290	2.320	2.341	2.349	2.356	2.363	2.368	2.373	2.377	2.381	2.385	2.391	2.397
12 Teeth	*A*	1.626	1.661	1.684	1.700	1.707	1.712	1.717	1.721	1.725	1.728	1.731	1.734	1.739	1.743
	R	2.396	2.448	2.482	2.505	2.516	2.523	2.530	2.536	2.542	2.547	2.552	2.556	2.563	2.569
14 Teeth	*A*	1.718	1.756	1.782	1.799	1.807	1.812	1.818	1.822	1.827	1.830	1.834	1.837	1.842	1.847
	R	2.532	2.589	2.626	2.652	2.662	2.671	2.679	2.686	2.692	2.697	2.703	2.707	2.715	2.722
15 Teeth	*A*	1.760	1.801	1.827	1.845	1.853	1.859	1.864	1.869	1.874	1.878	1.881	1.884	1.890	1.895
	R	2.594	2.654	2.692	2.719	2.730	2.739	2.748	2.755	2.761	2.767	2.773	2.777	2.785	2.792
16 Teeth	*A*	1.801	1.843	1.870	1.889	1.897	1.903	1.909	1.914	1.919	1.923	1.926	1.929	1.935	1.940
	R	2.654	2.715	2.756	2.784	2.795	2.804	2.813	2.820	2.827	2.833	2.839	2.844	2.852	2.859

The height and curvature of the wheel addendum is computed according to the number of teeth in the pinion and the ratio of wheel to pinion. Radius *R* for the tooth curve is found by multiplying the appropriate *R* factor in the Table B.S. 978 Part 2, by the module. The height *A* of the addendum is found by multiplying the appropriate *A* factor by the module. For example, in Fig 209 a pinion of 12 is driven by a wheel of 36. At the intersection of the horizontal line for the ratio and the column *A* for 12 leaves is the factor which, multiplied by the module of 0.2 mm, gives a height of 0.325 mm for the addendum. The radius of curvature *R* of this addendum is found by multiplying the module with the figure at the intersection of the horizontal line for the ratio and the column *R* for 12 leaves and is found to be 0.479 mm.

The dedendum *D* is equal to the addendum while the width *W* is $\frac{CP}{2}$.

The pinion dedendum is $(A + 0.4)M$, while the tip is formed according to the number of leaves, as shown in Fig 198.

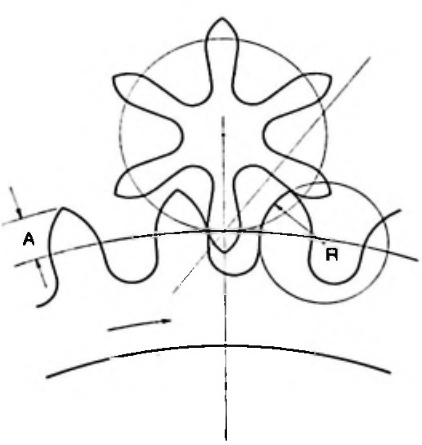
A more precise curve is used in the Swiss watchmaking industry. It is similar to the English system as manufactured by Messrs. Smiths Industries, see Table BS978. In Fig 204 the centre of radius *R* for this system is determined by a factor obtained from the manufacturing tables for the gear ratio and the number of leaves in the pinion. Reverting to Fig 202, the height of the constant addendum for the 6:1 ratio is $1.35 \times M = 0.27$ while that for the BS 978 is $M \times 1.303 = 0.260$ mm, a difference of 0.01 mm. For the 3:1 ratio the constant addendum is again $1.35 \times M = 0.27$ mm while that for



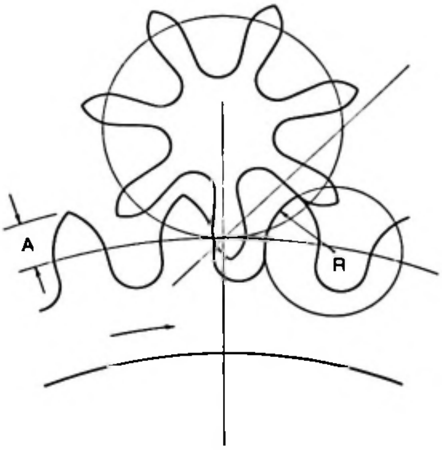
R = BS978 ratio/factor × M

204 Derivation of variable addendum

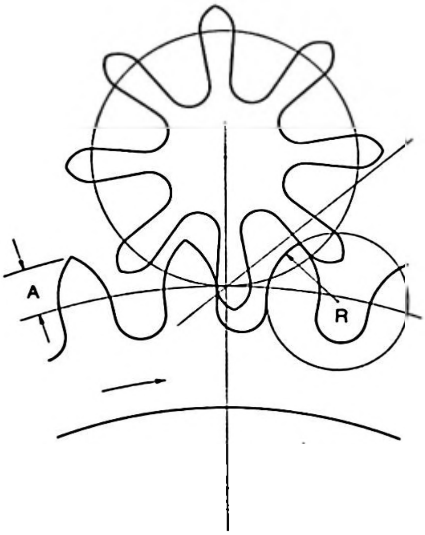
the BS 978 is 1.626 mm × M = 0.325 mm, a difference of +0.055 mm. Because the radius of the lower ratio addendum is greater the curve will be shallower and nearer the true epicycloid. For the same module the change in curvature with change of ratio is shown in Figs 205 to 209.



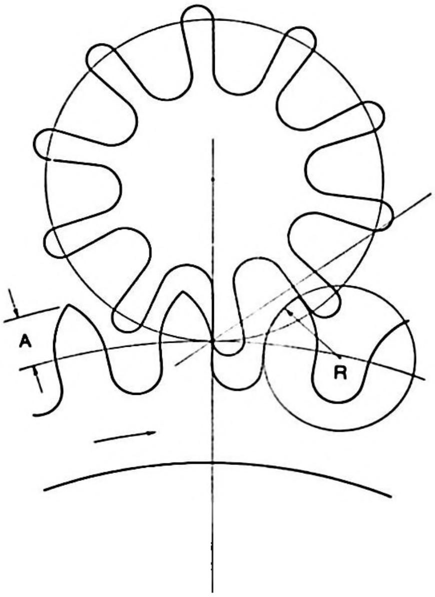
205 Addendum for 6-leaf pinion:
Ratio 6:1
Module 0.2
A factor = 1.303
R factor = 1.920



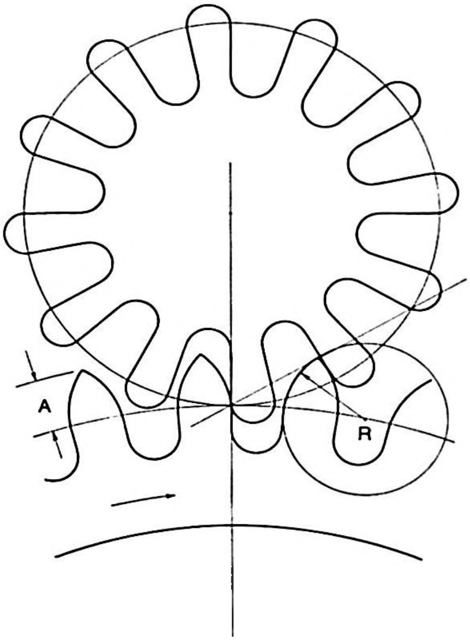
206 Addendum for 7-leaf pinion:
Ratio 5.1:1
Module 0.2
A factor = 1.374
R factor = 2.025



207 Addendum for 8-leaf pinion:
Ratio 4.5:1
Module 0.2
A factor = 1.438
R factor = 2.120



208 Addendum for 10-leaf pinion:
Ratio 3.6:1
Module 0.2
A factor = 1.540
R factor = 2.270



209 Addendum for 12-leaf pinion:

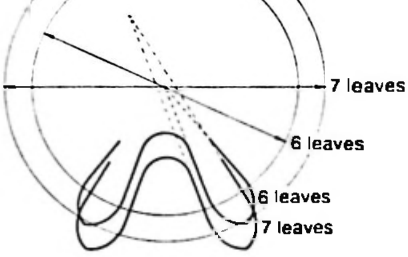
Ratio 3:1
Module 0.2
A factor = 1.626
R factor = 2.396

It might be thought that since the BS 978 system requires a different cutter for each ratio then it would be better to use true cycloids. This would be so if it were possible to produce precise cycloidal curves to a scale suitable for watches but this is impracticable. If it could be done then further difficulties would arise from the necessity for an equally precise engagement of the pairs to ensure a good lead. Deep engagement would cause excessive action at the tips of the wheel teeth and a shallow engagement would cause excessive action before the centre line. Both would be particularly severe with low-numbered pinions and for any number would be more pronounced than would be the case with the ogival derivatives with relieved tips.

When the origins of the cutter are known the wheel blank can be turned to the correct full diameter and the cutter passed through at a depth that will allow the curves to meet without reducing the diameter of the blank. When the origins of the cutter are not known the full diameter is best determined by trial on a test blank.

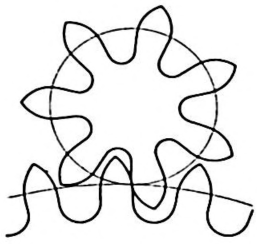
Pinion Cutters

Correctly formed pinions require a different cutter for every change in diameter and number of leaves. The constant addendum wheel cutters, described earlier, have complimentary pinion cutters but these are limited to cutting only two numbers for any module. The reason for this is shown in Fig 210 where two pinions of 1.2 mm with 6 leaves and 1.4 mm with 7 leaves have been cut with a 0.2 mm module cutter. The root space and the leaf thickness at the pitch circles are the same but the root width of the leaf is wider for the larger pinion. This inevitably means that the flanks are not radial and the lower the number of leaves the greater will be the departure from uniform velocity ratio.



210 Pinions require individual cutters

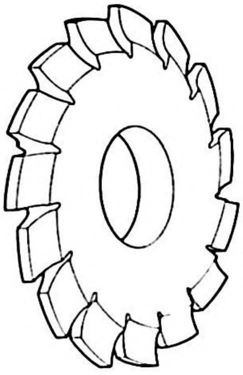
For the BS 978 system each pinion requires a different cutter the form of which is determined by the gear ratio and number of teeth.



211 Addendum for driving pinion

Pinion Addendum

When the drive is sometimes reversed so that the pinion drives the wheel the pinion will need addendum. The necessary increase in leaf width is compensated by a reduction in tooth width; both tooth and leaf being equal at 1.413 × M, as in Fig **211**. The addendum height is a function of the number of teeth in the wheel and pinion respectively. The depth of the dedendum is 1.75 × M. For the motion-work of watches, where the cannon pinion and minute nut are drivers, the wheels will be satisfactory if cut with a normal cutter of 1.72 × M. The pinions will need a correctly formed cutter to prevent excessive undercut of the flanks. If the power transmission is high both wheel and pinion should be made with cutters especially formed to suit their numbers and velocity ratio.



212 Constant profile cutter

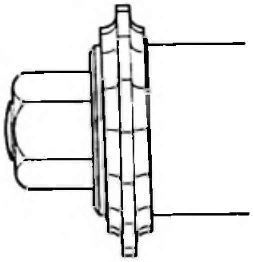
Wheel Cutters

Boxes of sized cutters can be bought from material shops. These are often marked in millimetres of tooth space. The appropriate cutter is selected by:

$$\frac{\text{Pitch circle}}{\text{No. of teeth} \times 2} = \text{tooth width.}$$

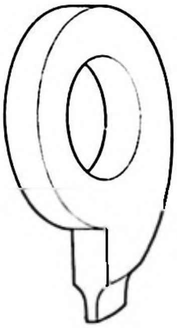
Such cutters usually have the old-fashioned, finely serrated cutting edges and so cannot be sharpened. The addendum is usually 1.2 × tooth width because the teeth are not tip-relieved.

The most useful type of cutter is the constant profile, milling cutter, shown in Fig 212. This can be sharpened without change in the tooth shape. Because the relief at the sides of the cutting edges is small the cutters must be kept very sharp. If traces of brass can be seen at the sides then the cutter is not sharp enough and the final cut may deform the first and last tooth of the wheel. The cutters should be checked for wobble, which would cause a wide cut and consequently narrow teeth. A wobbling cutter can be trued by packing with paper at the appropriate place, as in Fig 213. Alternatively, for special purposes, the tooth space can be widened by selecting a narrower cutter and packing to introduce wobble.



213 Increasing the width of cut

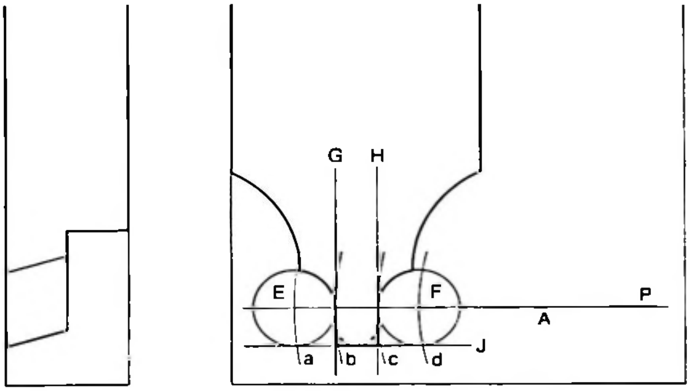
Hobbing cutters are used for quantity production. The cutter is in the form of a cylinder with spiral teeth. It is rotated as it traverses a stack of wheel blanks, also rotating, but at nearly 90° to its axis. These complex and costly cutters with their attendant machines are used for quantity production of wheels.



214 Fly cutter

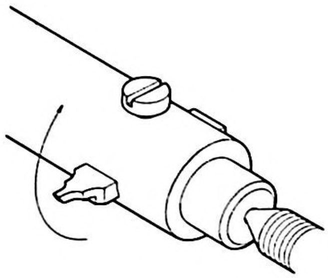
In an emergency a single edge, or fly cutter, can be used for wheel cutting. When such a cutter is needed it is usually to cut a replica of a damaged wheel. If so, then the form can be filed to fit an existing tooth space of the damaged wheel. Fig 214 shows a typical fly cutter.

If no pattern is available ascertain the module from the existing pitch centres or determine the module required. Use the full ogival form for the addendum curves and the radius will equal the tooth width. On a piece of steel with a clean straight edge, see Fig 215,



215 Making a fly cutter

scribe the line *A* parallel to the edge. Make a chamfer *P* to take one point of a vernier gauge and set the gauge to, say, 25 mm. Scribe the arcs *a*, *b*, *c* and *d* with the sliding point, advancing the gauge by half the circular pitch for each successive arc. At the points of intersection of lines *a* and *d* with *A* make deep chamfers for drilling. At points *b* and *c* scribe the lines *G* and *H* vertical to the edge of the steel. Drill holes *E* and *F*. Their radii will equal the radius of curvature of the addendum. Drill the holes slightly undersized and open to full diameter with a taper cutter from the back. This will leave a sharp edge to the cutting face with relieved sides for clearance. Scribe the horizontal line *J* to touch the edges of the holes. This will eventually indicate the root of the tooth. Cut away the surplus metal with a piercing saw and carefully file the dedendum up to the tangents *G* and *H* of the holes. Leaving the dedendum at the length indicated (twice the required addendum) will help to keep the file parallel to *G* and *H*. Finally cut along line *J* to define the root and make round if required. The dedendum edges will need backing off to meet the curve relief. Harden and temper the cutter and fit into a bar, as in Fig **216**. This method will ensure uniformity of the curves, which can be drilled to any suitable radius by calculation from the module factor.



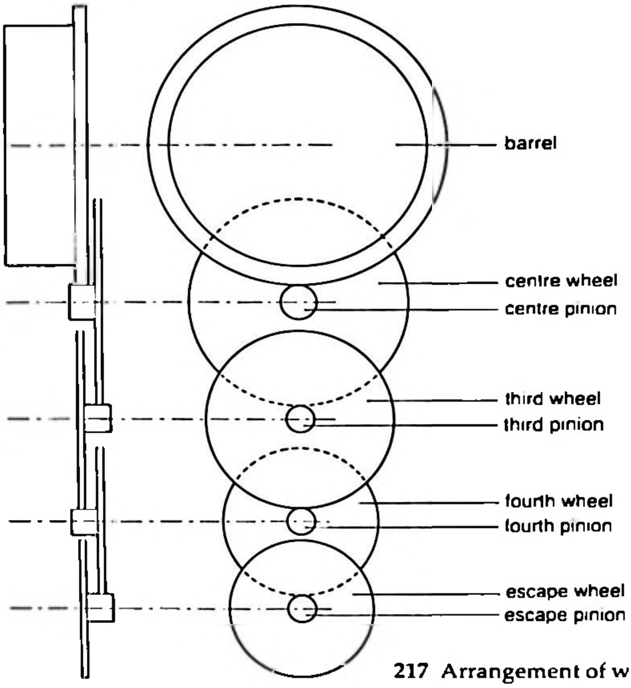
216 Fly cutter bar

Train Design

When designing a watch train consideration must be given to the ratio of each pair of wheels, the overall ratio of the whole train, the width of the teeth and the shape of the teeth. The number of wheels should be kept to the minimum necessary to achieve the required ratio with a smooth transmission of power. The ratio is the number of turns made by the driven wheel for one turn of the driver. If the driver has 75 teeth and the driven has 10 teeth then the ratio is $\frac{75}{10} = 7.5$ turns of the driven wheel to one turn of the driver. In watch trains the velocity of the driven wheel is always higher than the velocity of the driver so that there is a continuous increase in ratio throughout the train.

The conventional watch train has a mainspring barrel, three driving wheels with pinions and an escape wheel with pinion.

These are referred to as barrel, centre wheel, third wheel, fourth wheel and escape wheel. The centre wheel revolves once per hour and carries the minute hand. The ratio between the centre and fourth wheels is 60:1 and so the fourth wheel will carry the seconds hand. The number of turns of the barrel and escape wheel for one turn of the centre wheel is a matter for individual designers. The arrangement is shown in Fig **217**.



217 Arrangement of watch train

In calculating the overall ratio of the train it is necessary only to multiply together the ratios of the mating wheels and pinions. A common example would be: centre wheel of 80 teeth driving third pinion of 10 leaves, third wheel of 75 driving fourth pinion of 10 and fourth wheel of 80 driving escape pinion of 8. The individual ratios would be 8:1, 7.5:1 and 10:1 giving an overall ratio of 600 turns of the escape-wheel pinion for one turn of the centre wheel and expressed:

$$\frac{80}{10} \times \frac{75}{10} \times \frac{80}{8} = 600.$$

The ratio of turns of the centre pinion to turns of the barrel will be considered next. Since the centre pinion turns once per hour it will turn twenty-four times in a day. The centre pinion carries the greatest power loading and should be as large as is practicable to give strength to the leaves. It is also the slowest turning pinion and should have the highest number of leaves. 12 leaves would be suitable and a ratio of 8:1 would give 96 teeth. It happens that 96 and 12 is an exceptionally good ratio and will give near perfect transmission of power. The pitch diameters will need to be considered with the remainder of the train in relation to the space available.

The ratio between the fourth wheel and escape pinion will depend upon the number of teeth in the escape wheel which can, in turn, be influenced by the number of vibrations required per hour from the balance. If we consider the conventional arrangement of 15 teeth in the escape wheel for 18,000 vibrations per hour then:

$$\frac{18\ 000}{60 \times 30} = 10 \text{ turns of escape pinion}$$

where 60 is the centre to fourth ratio and the 15 escape-wheel teeth are doubled because each tooth represents one oscillation, or two vibrations, of the balance.

The overall ratio, excluding the barrel which does not affect the time, is now:

$$8{:}1 \times 7.5{:}1 \times 10{:}1 \times 30 = 18\ 000 \text{ vibrations}$$

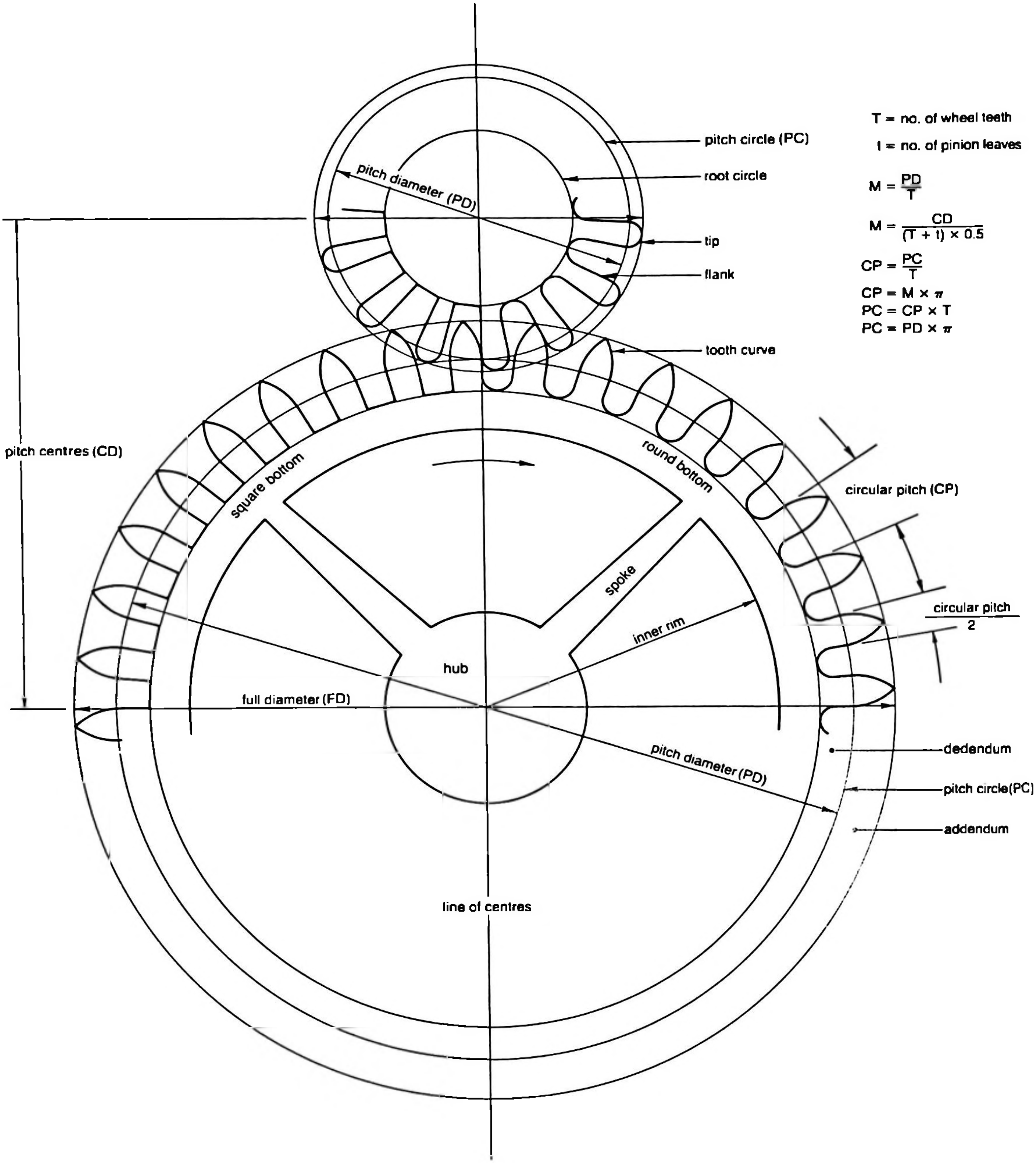
and so the ratios are satisfactory. They must now be expressed in terms of pitch diameters and numbers of teeth to suit the space available in the watch.

The millimetre is the most useful unit of measure for watchmaking. Cutters are usually marked in millimetres of tooth space or in modules of wheel diameter. Fig 218 gives the names of the parts of a wheel and pinion and the initial letters of the calculable variables.

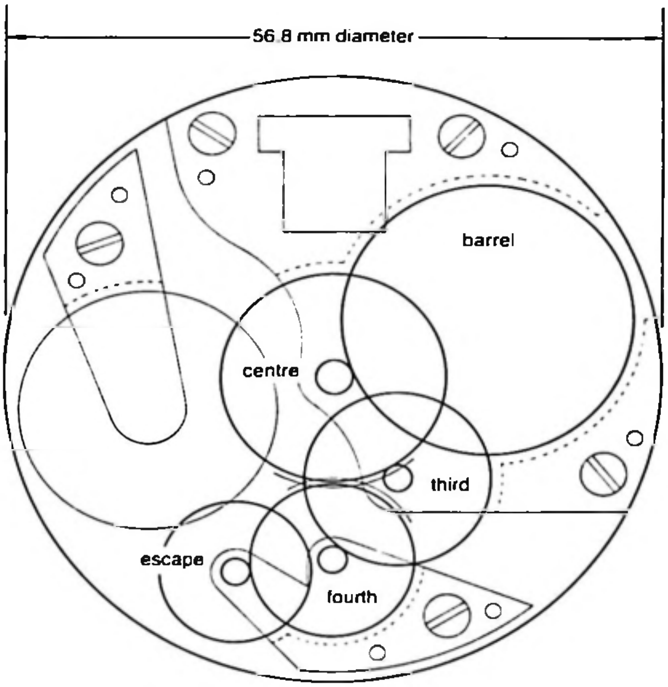
Fig 219 shows the layout of a conventional watch. It is required to determine the pitch diameter, full diameter and number of teeth in each wheel and pinion. The most suitable ratios have been determined on the basis of proximity to each other to spread the total ratio evenly throughout the train.

The diameters of the wheels have been chosen by proportion to fit into the space available without crowding. A large part of the area of the plate must be kept free to allow secure footings for the cocks and bridges. These are marked in dashed line to show the recesses and clearances for the diameters of the wheels. The circles representing the wheels are pitch circles and will be increased in diameter when the tooth addendum is included. It is particularly important to remember this when deciding on the relative sizes of the wheels. It can be seen that an addendum to the centre and fourth wheels will result in the teeth overlapping. This does not matter because the fourth wheel is below the level of the centre wheel. It is a different matter between the fourth wheel and third pinion. In the drawing there is ample clearance between the pitch circle of the wheel and the pitch circle of the pinion. It might be thought that the wheel could be larger, but when the addendum to the teeth and the tips to the pinion leaves are added this clearance will be at a minimum.

It is convenient to make the drawing to a large scale and in the following example, for a movement of 60 mm diameter, a drawing of twice actual size will suffice. The approximate pitch diameters will be taken from the drawing and for smaller movements an increase in scale would be useful. The abbreviations refer to Fig 218.


T = no. of wheel teeth
t = no. of pinion leaves
$M = \frac{PD}{T}$
$M = \frac{CD}{(T + t) \times 0.5}$
$CP = \frac{PC}{T}$
$CP = M \times \pi$
$PC = CP \times T$
$PC = PD \times \pi$
pitch circle (PC)
root circle
pitch diameter (PD)
tip
flank
tooth curve
pitch centres (CD)
square bottom
round bottom
circular pitch (CP)
$\frac{\text{circular pitch}}{2}$
spoke
inner rim
hub
full diameter (FD)
pitch diameter (PD)
dedendum
pitch circle(PC)
addendum
line of centres

218 Calculable variables of wheels and pinions



219 Plan of conventional wheel train

The Third Pinion

Taken from the drawing the pitch diameter of the centre wheel is 20 mm. The ratio of centre to third pinion is 8:1.

$$\frac{20}{8} = 2.5\ PD \text{ for the pinion}$$

The tooth numbers should be kept as high as possible since the centre is relatively slow-moving. If a pinion of 10 were chosen the action would occur after the centre line and the transmission would be smooth. The numbers are inversely proportional to the ratio of turns and so 8 × 10 = 80 is the number for the wheel.

$$PD \times \pi = PC \text{ and } 20 \times 3.142 = 62.84\ PC$$

$$\frac{PC}{T} = CP \text{ and } \frac{62.84}{80} = 0.7855\ CP$$

$$\frac{CP}{2} = \text{tooth or space since these are equal}$$

$$\text{and } \frac{0.7855}{2} = 0.39275 \text{ or } 0.39 \text{ tooth thickness}$$

$$\text{Briefly } \frac{20 \times \pi}{80 \times 2} = 0.39$$

A cutter 0.39 wide is needed to cut 80 teeth in a wheel 20 mm pitch diameter. The cutter may not be marked with a tooth width in millimetres but marked instead with a module in millimetres.

$$\frac{PD}{T} = M \text{ and } \frac{20}{80} = 0.25 \text{ module}$$

$$\frac{M \times \pi}{2} = \text{tooth width, and } \frac{0.25 \times 3.142}{2} = 0.39275$$

Briefly $M \times 1.57 = 0.39275$ or 0.39 tooth width

This is a suitable tooth width for a large watch in which the wheel will be 0.6 mm thick. If a pinion of 12 teeth were considered, the tooth width would be reduced to 0.32 and this would be insufficiently strong for the mainspring power required.

The pitch diameter of the pinion is 2.5 mm

$2.5 \times \pi = 7.855\ PC$

$\frac{PC}{t} = \frac{7.855}{10} = 0.7855\ CP$, the same as the wheel

The width of the leaves cannot be half the circular pitch as was the case with the wheel teeth. Clearance is necessary to ensure freedom of the wheel teeth as they pass through the pinion spaces. If the clearance were the minimum necessary to give freedom then binding might be caused by dirt and small hairs falling into the teeth. For this reason ample backlash is allowed by reducing the width of the leaves. For pinions of 8 or fewer leaves the width is one-third of the circular pitch. For pinions of 10 and more leaves the width is four-tenths of the circular pitch. The increased width for the higher numbers gives added strength to the slower moving pinions which are better able to resist the obstruction of foreign matter falling into the teeth.

In terms of CP then:
$0.078 \times 4 = 0.312$ mm leaf width at the pitch circle

In terms of the module then:
$M \times 1.25 = 0.312$ mm

The module for the pinion will, of course, be the same as for the wheel, that is:

$\frac{2.5}{10} = 0.25$ module

In round figures and with a tooth width of 0.39 mm and a pinion leaf width of 0.31 the backlash will represent 0.08 mm or approximately one-tenth of the circular pitch. Because the flanks of the pinion leaves are radial the width will reduce to the root where it will be approximately one-third narrower. Obviously a circular bottom will be stronger than a square bottom, as can be seen in Fig 218. Whichever is chosen the strength will be adequate for a third pinion where the power loading is eight times lower than that borne by the centre pinion. It should be noted also that pinion leaves are axially longer than the thickness of the driving wheel and this adds considerably to their strength.

Consider again the possibility of using a 12-leaf pinion where the module is 0.208 mm. This would give a leaf width at the pitch circle of 0.260 mm and at the root, approximately 0.173 mm. This would be too thin for a large watch and the chosen numbers of 80 and 10 would be better.

The Fourth Pinion

Taken from the drawing the diameter of the third-wheel circle is 16 mm; the ratio of third to fourth is 7.5:1; and the third is smaller in diameter than the centre but the ratio is lower and a pinion of 10 can again be considered:

$$\frac{75}{10} = 7.5 \text{ and so the wheel will have 75 teeth}$$

The module is 0.213 and the tooth width will be 0.33 mm. The pinion leaf at the pitch circle will be 0.26 mm and 0.173 mm at the root.

The Escape Pinion

The fourth wheel to escape pinion ratio is higher at 10:1 but the wheel is smaller than the third wheel. If a pinion of 10 is again considered then the wheel will have 100 teeth for a nominal diameter of 14 mm. The module is 0.14 mm giving a tooth width of 0.219 mm and a pinion leaf of 0.175 mm at the pitch circle and 0.116 mm at the root. The backlash for a 10-leaf pinion is approximately one-tenth of the pitch or 0.04 mm approximately. The loading of the pinion is very light and the width of the leaf is more than adequate. The backlash would be sufficient under perfect running conditions but, for a fast-moving, lightly loaded pinion it would be better increased to allow for the possibility of foreign matter falling into the teeth. The celebrated Abraham-Louis Breguet, whose work is renowned for its long-running reliability, never used fine teeth in his watch trains. To avoid their use in very small watches he sometimes included an extra wheel and pinion to reduce the ratios and enable the use of coarser teeth. The example of successful makers is always worth noting and a wheel of 80 with a pinion of 8 might be better. The width of pinions of 8 and fewer leaves is one-third the circular pitch to give increased backlash while the reduction in the number of teeth will give wider tooth spaces.

For the same pitch diameter of 14 mm the module is 0.175 mm, giving a tooth of 0.274 mm and a leaf of 0.164 mm. Both tooth and leaf are longer but the circular pitch has risen from 0.43 mm to 0.54 mm to give backlash of 0.092 mm as compared with 0.04 mm for the wheel of 100 with pinion of 10. The engagement of the wheel tooth with the pinion flank will occur approximately one-third of the leaf width before the centre line with an 8-leaf pinion. This is a very small disadvantage when compared with the increased running clearance and is quite acceptable in the fast-moving escape pinion.

The inertia of the fourth wheel should be considered for it must accelerate rapidly if the escape wheel is to be kept in close contact while impulsing the balance. The effective mass of the wheel is almost wholly in the rim and teeth. Its effect on the acceleration of the wheel will be proportional to the mass and as the square of the radius of gyration. It would be useful to reduce this effect.

If the wheel were reduced to 12 mm pitch diameter there would be a reduction both in weight and radius of gyration. The module would be 0.15 mm giving a tooth width of 0.235 mm and a leaf width of 0.157 mm for a circular pitch of 0.471 mm. The backlash would be 0.079 mm which is adequate although not so large as with the 14 mm wheel. This is a small loss compared with the advantage of the reduced inertia and the 12 mm wheel would be the best compromise.

The Centre Pinion

It remains to consider the barrel and centre pinion ratio. The pitch circle of the barrel is 25 mm diameter and the ratio is 8:1. With this ratio the barrel will complete three turns in twenty-four hours and, for the required thickness of mainspring, will yield six turns. A wheel of 96 driving a pinion of 12 will give a smooth transmission and this is particularly important at the barrel. The teeth must also be the strongest in the train because they have the greatest load to bear. Unlike the train wheels the barrel has considerable depth and so the teeth can be axially long to give increased strength.

The module for a barrel 25 mm diameter with 96 teeth is 0.26 mm giving a tooth width of 0.409 mm and a leaf width at the pitch circle of 0.327 mm for a circular pitch of 0.818. The backlash is 0.082. Experience has shown that these figures are quite satisfactory and give adequate strength to both wheel and pinion.

For a change in the size of the watch some or all of the dimensions will need to be changed and the changes will depend upon the change in scale. The experience necessary to make changes in the ratios and dimensions of trains can only be acquired through practice or observation of the methods used by experienced watchmakers.

The examples given will serve as a guide to the method of arriving at the most suitable dimensions and numbers for the wheels and pinions. The conclusion can be expressed as:

$$\frac{80}{10} \times \frac{75}{10} \times \frac{80}{8} \times 30 = 18{,}000$$

remembering that the 15 teeth of the escape wheel must be doubled.

If it is desired to change the number of teeth in the escape wheel, while continuing to indicate seconds, then a change must be made in the fourth wheel to escape pinion ratio. Thus:

$$\frac{80}{8} \times 30 = 300 \text{ vibrations per minute}$$

$$x \times 40 = 300 \text{ vibrations per minute}$$

$$\frac{300}{40} = 7.5{:}1 \text{ fourth/escape ratio}$$

$$\frac{60}{8} \times 40 = 300 \text{ vibrations per minute}$$

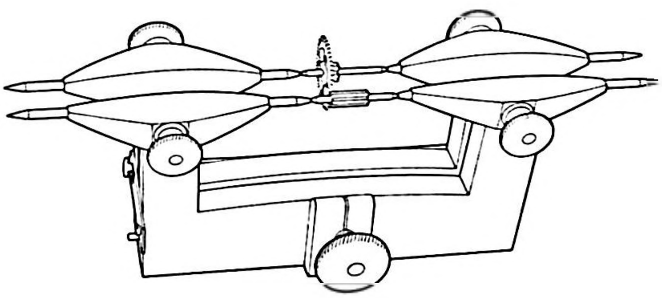
Some modern escapements vibrate 36,000 times per hour and employ the 20-tooth escape wheel and $\frac{600}{40} = 15{:}1$ fourth/escape ratio.

If a pinion of 8 were selected the wheel teeth would be too fine for a small watch. 6 would be better and $\frac{90}{6} = 15:1$ and $\frac{90}{6} \times 40 = 600$ vibrations per minute.

Depthing

Unless the true centre distance is known from previous experience of the wheels and pinions it is unsafe to find the distance by calculation. The curves of the wheel teeth are a compromise depending on the ratio and number of teeth and it is impracticable to measure the true diameters of the pitch circles. If the pinion leaves are truly radial their pitch diameter will be determined by the effective pitch diameter of the wheel. This is best found by running the wheel and pinion together and adjusting the depth of their engagement to produce a smooth action without drop or binding.

The depth tool is the most convenient means of finding the best engagement for the wheel and pinion and marking off the distance. It is shown in Fig 220 with the wheel and pinion fitted into the female runners. If the ends of the pinion leaves have become rounded with polishing, shorten them so that the full diameter can be observed in the tool. Adjust the runners to bring the face of the pinion level with the face of the wheel. Ensure that both wheel arbor and pinion are quite free to turn without shake. If the pinion is at all tight in the runners the action could be jerky and lead to a false impression of the engagement.



220 Depth tool

Apply slight friction to the pinion arbor with the thumbnail and turn the wheel while observing the action with a glass. The engagement of the pinion leaf should occur on or before the centre, depending on the number of leaves in the pinion, while the departing tooth is still safely on the flank of the departing leaf. If contact occurs too early the depth of engagement is shallow and the action will bind. If too late the engagement is too deep and the approaching tooth will drop on to the leaf. Both faults cause loss of power, the first by the sliding friction of the engagement and the second by forcing the line of thrust away from the pitch circle.

When satisfied that the action is correct roll the wheel under the pad of the finger. It should be quite smooth. If it feels 'notchy' alter the depth and try again, first one way and then the other with the thumbnail resting lightly on the pinion arbor. If the action is smoother after adjustment re-examine the depth and note the point of engagement and departure of the teeth for future reference when making the initial setting. If the depth cannot be made smooth then the velocity ratios are incorrect and the sizes must be reconsidered.

It should be noted that a smooth action can be achieved even though the pinion is incorrectly sized. A pinion that is too large will engage before the centre line to cause a 'notchy' action. The pitch circle is too large and the leaves are too far apart. Bringing the wheel closer to engage the pinion at a smaller pitch diameter will cure the fault but there is a danger that the tips of the pinion may foul the approaching wheel tooth and stop the train. If the engagement is late the wheel will accelerate to the point of contact. The pitch diameter is too small and the leaves are too close together. Reducing the depth will effectively increase the pitch circle diameter of the pinion but there is a danger that the tip of the wheel tooth may advance too far along the pinion leaf to cause the following tooth to drop into engagement.

Judging a good depth and the quality of its action inevitably requires experience. The student will not have this experience but the illustration of engaged pairs shown in Figs **205** to **209** at the moment of lead transfer will help him to understand the requirements as well as to recognize them.

When the depth is satisfactory the centre distance is marked on the plate with the points of the runners. Remove the wheel and pinion and set the pointed ends of the runners level by bringing them vertically on to a flat plate. If this is done on a polished surface the reflection will indicate if the tool is upright. Alternatively a square edge alongside the tool will help. If the tool is not upright the centres will not be correct. When one of the centres has already been drilled or is in a recess the tool must be set upright with one point in the drilling or recess. Scribe an arc with the free point of the tool. The drilling for the depth can be made at any selected point on the arc. The exact point will be determined by the pitching of the next wheel.

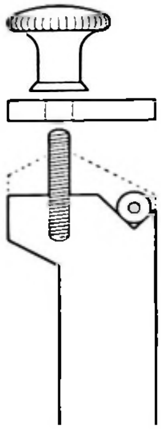
Depth Tool

The tool should be checked for alignment and parallelism of the runners. No errors are permissible for they will reproduce as variable errors of pitching. Ensure that the runners and their holes are quite free of dirt that would cause stickiness. Check that they pass easily through their holes without binding. The runners should also be checked to reveal any eccentricity of the centres or bowing throughout their length by rotating them between fixed centres. If the points have been badly sharpened they will need grinding true.

Check the alignment of the runner holes by scribing arcs with points alternately at the inner and outer ends. Drill a hole 0.2 mm diameter in a piece of brass plate and stone the surface clean and flat. Place the point of one runner in the hole and scribe an arc. Next place a point at the opposite end of the tool in the hole and continue the arc. Do the same with the inner ends of the tool by reversing the runners to bring the points inside.

If the tool is true the arcs will ioin into a continuous line. Any break in the line will indicate an error of alignment of the ends of the tool. It is very rare to find a tool that will pass this test and the fault usually lies in want of parallelism of the two halves of the tool. To correct the error it will be necessary to set the drillings parallel by twisting the heads. Even if the position and extent of the error can be determined the correction will be difficult to make for it will need to be done in two parts, the first to make the runner or runners parallel and the second to align them. Unless some means of accurate measurement is available the task will become an endless fumble with no certainty of success.

Some tools have the runners sliding in grooves cut into the tops of the heads, as shown in Fig 221. It is a simple matter to convert a faulty tool by this method and the alignment is assured.


221 Modified depth tool runner

Cut the grooves to the minimum width and depth required to take blued-steel rod slightly larger in diameter than the original runners. With the caps fitted the runners must fit the grooves without visible freedom and without binding. Secure the caps with screws each side of the locking-screw holes. Turn a point at one end and drill a safety centre at the other. These centres will be more serviceable than the conventional cone centres and will support delicate arbors without risk to the pivots. Harden the tips of the runners only, by holding them low over oil while heating to bright red before plunging. Polish with a smooth buff stick while supported in a groove to avoid risk of bowing.

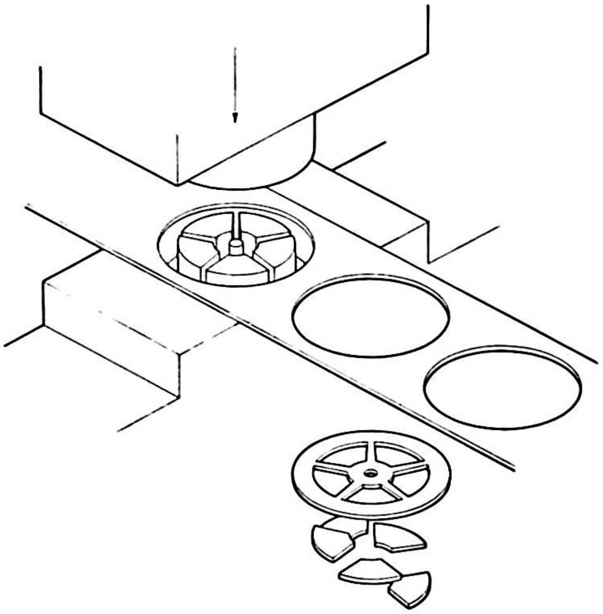
A good depth tool is essential to the watchmaker and should be treated with care. It is easily damaged by accident and should be returned to its box after use and never left lying about the bench.

Wheel Cutting

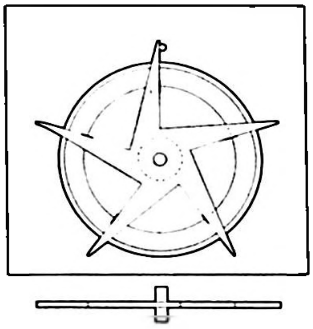
Preparing the Blanks

The wheels should be crossed out before the teeth are cut to avoid possible distortion of the rim. The crossings need not be finished but the bulk of the unwanted metal should be removed. The three basic methods of doing this are stamping, sawing or routing. Stamping is the neatest and most precise method. It is also the least practical for crossing individually sized wheels because every change of size needs a different punch and die. The principle is shown in Fig 222 where the wheel material is fed into a die and the unwanted metal is punched out at a single stroke by an accurately fitting punch. The tools are costly to make and clearly not economical unless many hundreds of wheels of a particular size are needed.

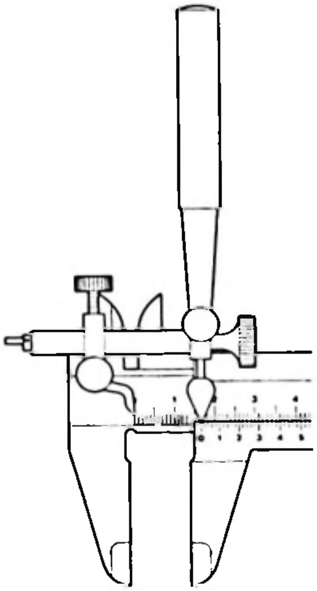
Sawing is more practical and, although somewhat tedious, can be done quite quickly and neatly. It will be necessary to scribe the outline of the wheel on the material to be used. The marking jig shown in Fig 223 will equally space the spokes of a variety of



222 Wheel blanking tool



223 Spoke spacing guide



224 Setting a compass with a vernier gauge

differently sized wheels. It is made from steel and has a short post at the centre. A train wheel of brass, 14 mm pitch diameter with 75 teeth, will be considered. Cut a piece of sheet brass of the appropriate thickness, say 0.45 mm. Cut the sheet with the piercing saw to avoid curling the edges. If a rolling mill is available the sheet can be cut with shears and lightly rolled to ensure flatness. Drill a hole to take the post of the marking jig. Stone both sides of the brass to a clean surface with water-of-Ayre stone. Find the full diameter of the wheel from the module factor, say, 1.35 mm. Therefore $N + 2.7 \times M$ = 14.5 mm *FD*. Scribe the circle lightly using the post hole as a centre. Measure the circle and when satisfied it is a true diameter mark it more firmly on both sides of the material. The flank of the tooth will be the same height as the addendum and the root circle will be 13.5 mm diameter. The diameter of the inner rim is a matter of individual preference but 12.2 mm would look pleasing. The hub diameter will depend on the function of the wheel, but a 4 mm diameter will suffice. Hub diameters should not be made excessively small or they are likely to stretch when riveting the pinion. Scribe the circle. All circles should be clearly marked with a sharp compass on both sides of the material. A vernier gauge can help to set the compass as shown in Fig **224**.

At a distance outside the circle for the full diameter drill a small hole and push in a taper pin. Locate the peg of the marking jig in the centre hole with one limb against the taper pin. Make marks for the spokes where the limbs meet the inner rim circle. Rotate the jig by an amount equal to the required thickness of the spokes and make a second mark. Remove the jig and scribe the lines to meet the hub circle. Mark both sides in the same way, being careful to rotate the jig in the correct direction. All the dimensions of the wheel will now be marked out.

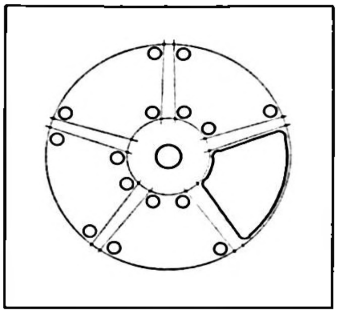
Drill holes, as in Fig **225**, and saw out the unwanted metal. The edges can be filed up to the scribe marks before or after the teeth are cut. The surplus metal is best removed in the lathe to ensure concentricity of the centre hole with the outer diameter. The chuck, shown in Fig **226**, is easily made by soldering a piece of standard rod into a brass blank and turning the face and edge true. The clamping plate has a conical hole at the centre and is secured by three screws.

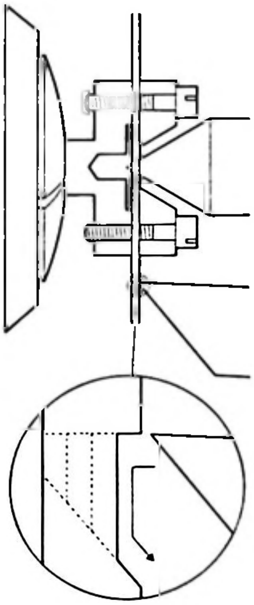
Put the chuck in the lathe with the blank loosely held by the screws. Bring up the tailstock and centre the blank by the jig-post hole and tighten the clamping plate to hold the blank firmly. With a sharp pointed tool turn a wide groove in the metal to part the unwanted edge from the blank. The parting cut must be made in several passes of about 0.2 mm depth and widened radially after each advancement of the point to relieve the pressure on the back edge and prevent chattering.

A more convenient way of making the crossings is to rout them out with a pantograph milling machine. These are sometimes called engraving machines. They will reproduce to the same or smaller scale the outline of a master pattern. If the master for a wheel blank were 100 mm in diameter than a blank of 14 mm diameter could be cut if the pantograph were set to a ratio of 7.14 : 1. It is necessary that the cutter diameter and the stylus diameter be in the same ratio. This can lead to complications because if it became necessary to change the blank diameter by, say, 10 per cent, the cutter or stylus must be changed to suit. A better plan is to make a composite master and change the components to suit a change in ratio. Fig 227 shows plan and sectioned elevation of a suitable composite master. The inner diameter of the rim is 100 mm and the spokes are 5 mm wide tapering to 4.5 mm at the tips. The hub, inner rim and full diameter circles can be changed for different sizes whose diameters vary by 2 mm increments. The pantograph ratio is chosen by reference to the width of spokes required. If the wheel of 14 mm pitch diameter is required to have spokes 0.4 mm wide when finished the blank should have a width of 0.6 mm to allow for cleaning off the cutter marks. This will give a ratio of 7.5 : 1. The hub circle will be 30 mm diameter and the inner rim 91.5. The circle for the full diameter will be 110 mm and this will be traced by the radius arm. The nearest useful diameter for the inner rim is 90 mm and this will reproduce a circle 12 mm diameter. The small difference will be useful for cleaning off the cutter marks.

The cutters can be made from silver steel rod hardened in oil and tempered to a pale-yellow colour at the root of the blade. Fig **228** shows the form of the cutter.

The blanks can be cut from as large a sheet of brass as the worktable of the machine can accommodate. Move the stylus along the edge of the master at a steady speed without jerking. Do not stop in the middle of a run for this will cause a hollow in the blank at the point where the cutter rested. This is not important for a wheel blank where the dimensions allow for cleaning up but it would be if the dimension from the cutter were final as is sometimes necessary.


225 Sawing out the crossings


226 Wheel blank chuck

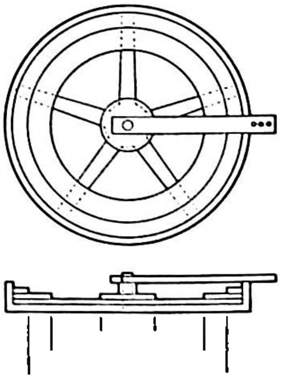
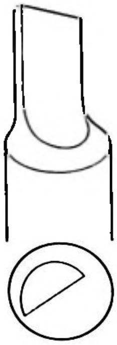
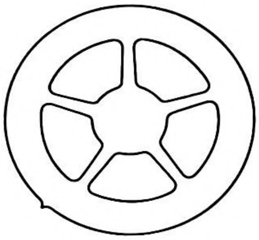

227 Pantograph master wheel

Fig 229 shows a typical blank. Clean both sides of the blank with water-of-Ayr stone to remove the cutter burrs, and the blank is ready for dividing.



228 Single-edged milling cutter



229 Wheel blank produced by pantograph

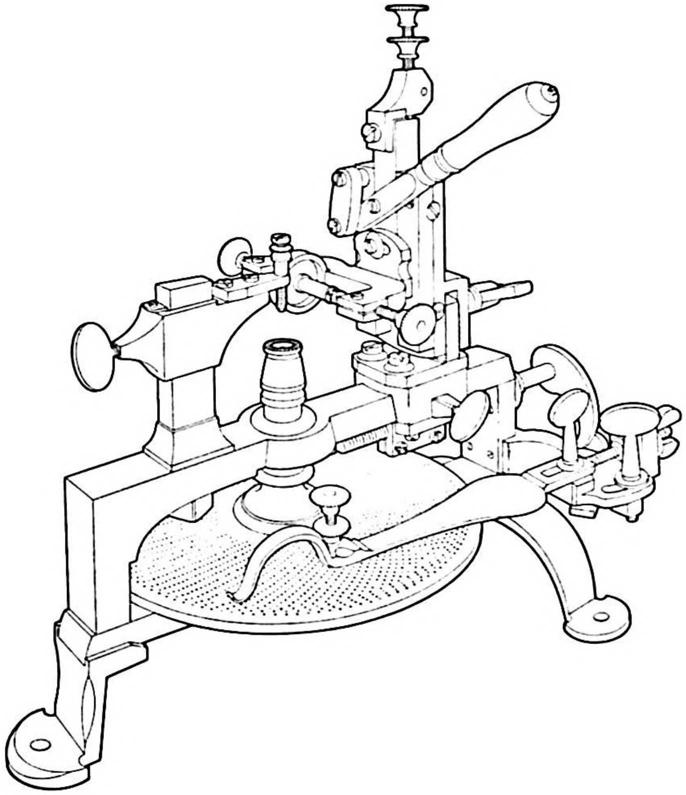
Cutting the Teeth

The blank must be supported close to the root diameter while the teeth are being cut. The work can be done in a wheel engine or in the lathe.

Fig 230 illustrates a typical wheel engine. The blank is laid on the chuck at the top of the index plate spindle and clamped down by a steel cone. The spindle has a tapered bearing in the top frame and a steel point in the bottom frame. If the gallows clamp is pressed down too hard on the blank the frame will spring and make the taper bearing slack. Adjust the bottom point so that the plate is stiff to turn. Working freedom can be restored by adjusting the pressure on the workpiece so that the plate turns easily but without side shake.

Centre the blank by tapping with a light hammer to bring the edge true with the chuck as the plate is rotated. Finally set the gallows clamp to hold the work firmly and allow the plate to turn easily. This is important. If the plate is at all stiff, the division holes will not self-locate under the index point and the division will not be accurate. Adjust the index to the radius of the required division circle and clamp the pivot firmly to prevent inadvertent shifting to an incorrect circle.

If the blank is exactly to size but not concentric the teeth on the shortest radius will not be fully formed. To avoid this possibility it is better to leave the blank oversized. After the teeth are cut measure the full diameter while the wheel is in the machine. Wheel engines of this type do not have accurate feed threads and so the cutter cannot be advanced an exact amount to bring the wheel to size. Advance the cutter by a small amount and measure after each cut until the full diameter is correct. Subsequent wheels of the same size can be cut without further alteration. This precaution is intended to guard against only the smallest possible errors of eccentricity. Any visually obvious eccentricity should be corrected first to preserve the general truth of the circles for the inner rim and hub.



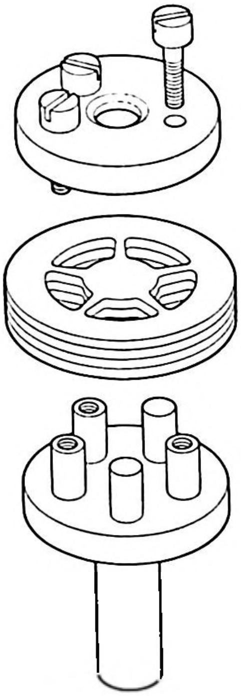
230 19th-century wheel-cutting engine

To true the centre hole, set the wheel with shellac into a turned recess in a wax collet in the lathe and make true and to diameter with a boring tool. The diameter of the hole will depend upon the pinion to be fitted. A suitable diameter allowing a secure seat for the wheel with adequate rivet would be $(t - 1.4) \times M$. This would make the rivet diameter two-thirds of the full diameter of the pinion.

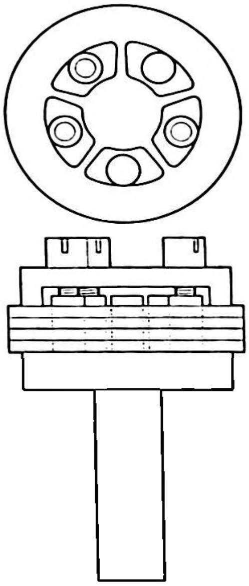
If the wheel is to be cut in the lathe it can be mounted in the chuck, as in Fig **231**, and turned to correct full diameter. After the teeth are cut, bore the hole true and to diameter and the wheel is ready for finishing.

The blanks made on the engraving machine do not need a centre hole. They can be located in the chuck by the inner rim, as shown in Figs **231** and **232**. In this way several wheels can be cut at one time. This means inevitably that a different chuck is needed for each change of inner diameter. If this is inconvenient the blanks can be held lightly in the chuck, and brought true by holding a flat edge against the rims, as in Fig **233**. Finally clamp firmly. The nib left at the rim by the cutting tool of the engraving machine must first be removed with a file.

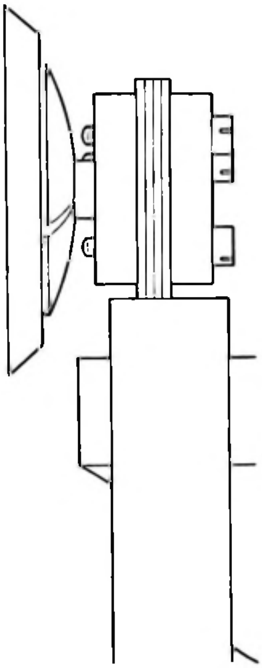
Turn the blanks to the correct full diameter and cut the teeth. Drill the hole for the centre and bore to correct size for the pinion to be fitted, that is $(t - 1.4) \times M$.



231 Multiple blank holding chuck



232 Blanks located on chuck



233 Centring the blanks

Indexing in the lathe can be done with the standard worm and wheel dividing attachment, but this is tedious with high-numbered wheels. It is better to make a plate with the required number of holes, and index them with a spring blade with a conical point.

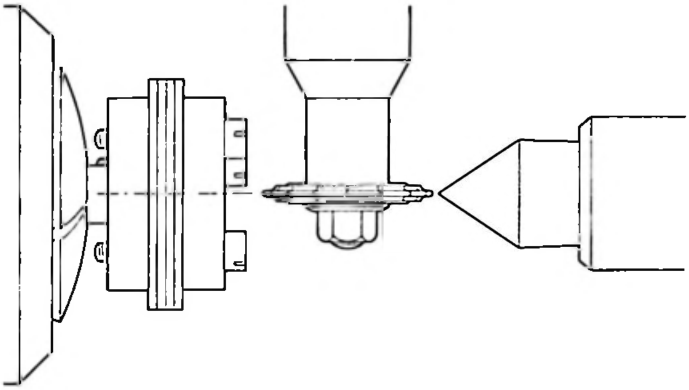
Make the plates from brass discs of about 100 mm diameter and 2 mm thickness with a collar with clamping screw at the centre. Hold in the lathe by the collar and bore the hole true to fit the headstock arbor of the lathe to be used for the wheel cutting. Fit up the drilling quill, as in Fig **741**, and drill through at 1 mm diameter with the number of holes required for the wheel teeth. Several circles of different numbers can be drilled in one plate at different radii.

While it is not difficult to subdivide a high-numbered circle to produce a wheel with a low number of teeth, nevertheless mistakes can happen and it is always better to have a correctly numbered circle for each different number of teeth required. Drilling right through the disc will prevent spacing errors arising from a hole blocked with swarf or other debris.

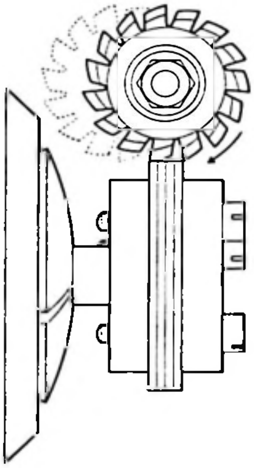
Alternatively the discs can be made with ratchet teeth or edge divisions located with a pivoted detent. This method is useful for rarely used numbers such as those used in sidereal to solar trains. Division plates for these can be made by using a strip of cinematograph film cemented into a circle of the required number of divisions. Fit the circle to a wood disc turned to correct size in the lathe and with a groove at its edge to allow a pivoted detent to enter fully and locate the disc. With a little care in entering the detent such a disc will produce a perfectly divided wheel.

Most lathe manufacturers will supply dividing plates for the general run of numbers and some will supply special numbers to order. Production toolmakers are usually equipped to make plates of any number of divisions.

The correct full diameter will have been calculated from the module factor for the cutter. Centre the cutter with the tailstock point, as in Fig 234, and then raise it to the level of the blank diameter, as in Fig 235. Advance the quill to the distance required to complete the cut, and lock the slide stop to prevent the cutter coming into contact with the headstock spindle. Bring back the quill ready for the first cut and lower the cutter by the height of the tooth × 0.75. Cut two adjacent teeth and continue to pass the cutter through the spaces while lowering after each two passes until the addendum curves meet at the full diameter. Cut the remainder of the teeth and the wheel is ready for finishing. Subsequent wheels can be cut without reference to the height of the cutter. For a standard cutter of 12 mm diameter a speed of 1,000 rpm is suitable for a feed of 10 mm per second.



234 Aligning the cutter



235 Setting the cutter height

When the centre distance is fixed and a wheel must be cut to suit, the module is:

$$\frac{CD}{(T + t) \times 0.5}$$

Leave the blank oversized by 0.1 mm. Produce the first tooth to the height of the full diameter as described and cut a further half-dozen teeth. Note the thimble setting before lowering the cutter by 0.02 mm to cut a further half-dozen teeth. Continue this process to produce a wheel of six different pitch diameters leaving a blank space between each change of cutter height to distinguish the different radii.

Fit the wheel to a trial arbor and check the engagement with the pinion in the watch frame. Select the best working radius, reset the cutter height as appropriate and cut a complete wheel. Knowing that the depth will now be perfect the wheel can be finished with confidence without possible waste of labour.

As the cutter passes through the blank it will leave burrs on the departing side of the teeth. These can be avoided by cutting two wheels at once and discarding the one on the departing side. When this is not possible the burrs can be removed with a flat water-of-Ayre stone used while the wheel is supported on a cork under running water. File the surface of the stone flat and clean and apply with a light pressure to avoid turning the burrs into the tooth spaces.

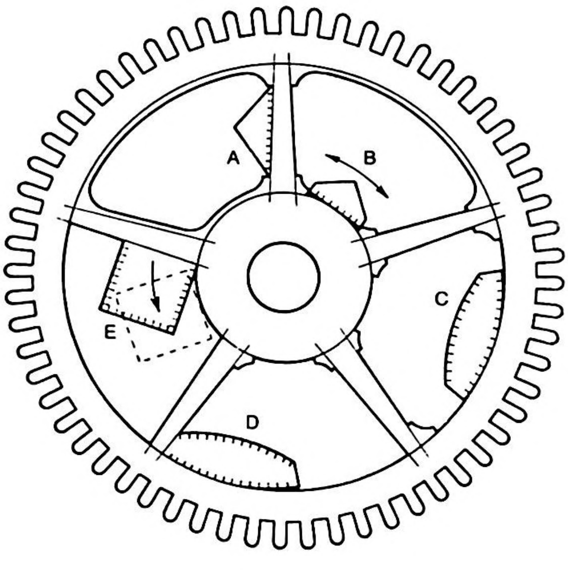
Finishing the Wheels

Blanks made on the engraving machine will need circles scribed on both sides to define the limits of finishing if the diameter of the inner rim and hub are not as required. If they are correct the circles will be useful to measure the progress of the work. If the blank was cut with a saw, attend first to the spokes but do not file them up to the corners.

Space *A*, in Fig **236**, shows the limits of the first cut made with a No. 6 barrette file. Reduce the width of a similar file by grinding and file the hub to the scribed circle. Space *B* indicates the limits of filing with the second file. The inner rim is taken back to the line with a double-rounded file with a curve to suit the rim as in space *C*.

237 Safety edges for the crossing file

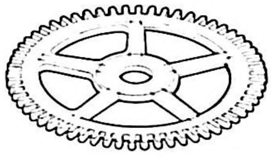
The corners must be ground smooth and flat, as shown in Fig **237**. This will waste one side of the file but if it is not finished in this way a sharp corner cannot be achieved and there is always the danger that the rough edge of the file will damage the spokes and ruin the work. The same file can be used for the corners of the inner rim by holding the safe edge against the spoke and cutting down to the rim as in space *D*. The corners of the hub are removed with a square file with one face ground smooth. Hold the safe edge against the spoke as seen in space *E*. When the corner meets the circle, tip the file and merge the flat into the circle.



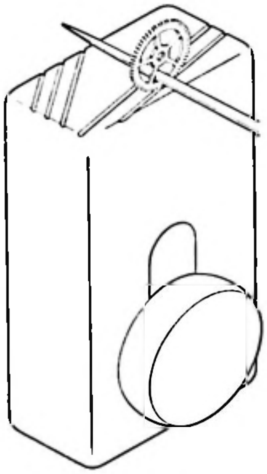
236 Finishing the spokes

It is a mistake to attempt to finish any edge separately and without reference to an adjacent edge. The files must be applied to each edge in succession until they meet in perfectly sharp corners. It is not always easy to see the scribe lines either because they are obscured by the shadow of the file or by the burrs thrown up. The lines will be more clearly defined if the corner of the work is bevelled up to it, as shown in Fig 238. Spokes may be filed uniformly narrower by the same method without the necessity of scribing new lines. When satisfied with the dimensions finish the edges by draw-filing and smoothing with hard wood and finely crushed oilstone paste.

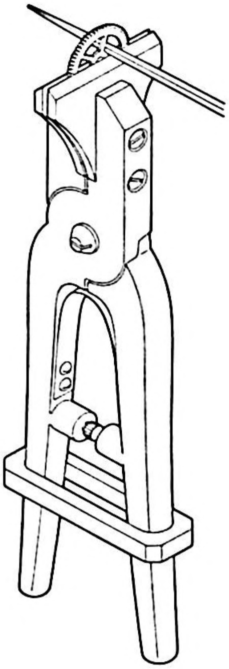
During the filing the wheel can be supported on a bench pin, as in Fig 239, for the rims, and in brass-jawed sliding tongs for the spokes and hub, as in Fig 240. Delicate wheels should be supported in a holder, as in Fig 241.



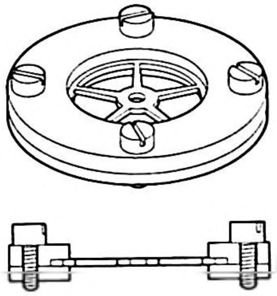
238 Reducing the width of the spokes



239 Filing the rim



240 Filing the spokes and hub

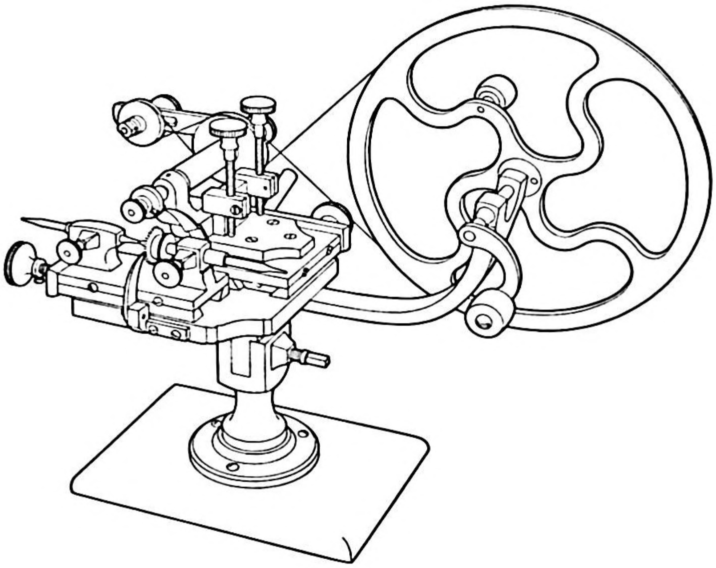


241 Holder for delicate wheels

Topping Tools

Early nineteenth-century Swiss watchmakers used a filing machine to alter the shape of the wheel teeth or to reduce the diameter of the wheel. The file was formed to fit the space between two teeth and guided axially to the wheel on rails. The file was passed to and fro between the teeth until a stop prevented further cutting. The wheel was then turned to the next space by hand and the process repeated. This machine was later developed into the automatic topping or rounding-up tool shown in Fig 242.

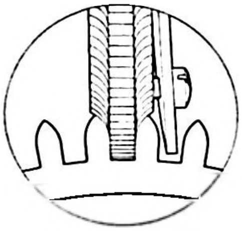
The wheel is fitted up between centres with the rim supported against the cutting pressures. The circular cutter in the form of a partial helix is rotated by a hand wheel. The helix has no teeth and



242 Wheel topping tool

can be adjusted to the circular pitch of the wheel. One tooth space is cut at each revolution and on completion of the cut the plain helix will enter the next space to turn it into the path of the cutter.

Fit the wheel between the centres without end shake but quite free to revolve. Ensure that the rim is close up to the back support without binding. Check that the wheel is free for a complete revolution. Variation in friction will allow irregularities in the cutter to cause variation in circular pitch of the wheel. Lack of symmetry in the taper running from the knife edge of the helix to the full cutting width of the teeth, causing partial deviation of the cutter path, is the most common cause of pitch variation. This fault is of no consequence if the wheel turns easily between centres.



243 Setting the cutter helix

Adjust the cutter so that the start of the helix is centred in a tooth space when the full width of the cut is to the full depth of the tooth space at the largest radius of the wheel, see Fig 243.

Check that the axis of the cutter is immediately above the edge of the wheel and the cutter edge is immediately above the axis of the wheel. The machines are usually fitted with pointers to locate the respective edges of the cutter and wheels. If not, the position can be checked by laying a straight edge across the face of the wheel to meet the cutter axis and across the cutter face to meet the wheel axis. In both cases make allowances for the thickness. It is most important that this adjustment is correct if tapered and sloping teeth are to be avoided.

Set the cutter almost to the depth of the tooth space by using the depth stop screw. Turn the handle very slowly at first to observe the correct path of the cutter through the space. Gradually lower with the stop screw until the cutter makes cutting contact for a full revolution of the wheel. When this happens the wheel is round and concentric with its arbor. If the wheel is to be reduced to obtain a correct depth with its pinion it should be tried frequently between light cuts.

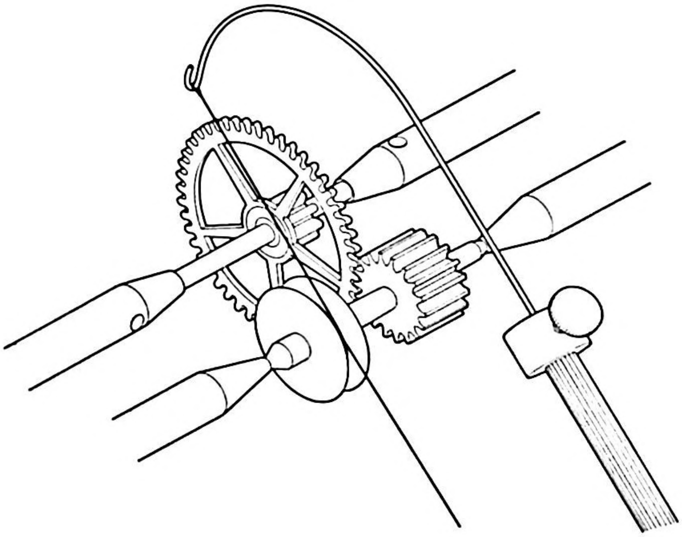
Some machines have two depth screws to enable a series of wheels to be gradually reduced by lowering with the first screw until the final depth is reached with the pre-set second screw. These earlier machines sometimes have a separate helix serving for a range of cutters. They are adjusted in the same way.

With a topping tool it is not necessary for the wheel to have shaped teeth before using the cutter. If the wheel has slots or gashes at its edge for the appropriate number of teeth the helix of the cutter will locate in the slot and the cutter will form the teeth. The cutters are no longer made but old sets frequently appear for sale. The tooth form produced is basically that used by the Swiss watch industry and from which the British Standard 978 form was computed.

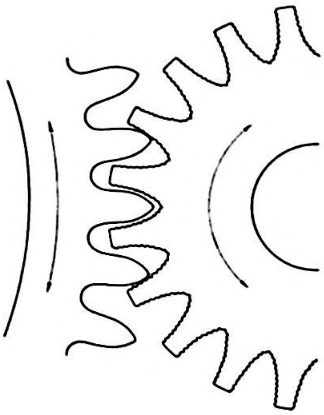
Ingold Fraise

A rare tooth-dressing tool is the Ingold Fraise. This is a steel roller grooved with sharp-ridged slots shaped to roll over the tips of the teeth. It is fitted by a taper to an arbor in a pivoted frame. The wheel is fitted between parallel centres and the teeth and roller brought into contact by an adjusting screw. The fraise is worked by a bow to cause the wheel to rotate in contact with the sharp flanks of the slots, as in Fig **244**. The cutter marks are radial to the tooth curve and produce a better working surface than the axial cutter marks produced by the topping tool.

Select a cutter that will fit over a centre tooth while resting on the flanking teeth, as in Fig **245**. Great care and some experience is necessary to select the correct cutter. When starting the work, closely observe the surface of the teeth in the early stages. If the fraise is too large it will cut ridges in the flanks of the teeth; if too small the curve will be ridged.



244 Ingold Fraise



245 Fit of wheel teeth to correctly sized fraise

Pinion Cutting

When making individual pairs of wheels and pinions it is advisable to make the pinions before the wheels. This is because the pinion, after machining, must be hardened and polished and this will affect its final dimensions. The wheel is easily matched to the finished pinion by adjusting its diameter to suit. The production engineer, working to fixed dimensions, will experiment to find the best dimensions of wheel and pinion to suit a fixed centre distance. The calculated dimensions of the designer may not be the final dimensions appropriate for production. When the prototypes are satisfactory the components can be made by the hundred thousand and each will be identical within the limits allowed for tolerance. In the making of individual watches by hand methods every depth is experimental and the watchmaker must develop the flexibility necessary to suit his circumstances.

The calculations for the train are based on nominal pitch diameters derived from the general arrangement of the components in the watch. The actual pitch diameter of the wheel or pinion cannot be seen and its measurement is impracticable. For all practical purposes it is imaginary and the final depth of mating pairs can only be determined by meshing the full diameters. If the final full diameters of the pairs were to agree with the calculated full diameters it would be unwise to presume the calculated pitch centres to be ideal. It is not important if the final diameters are a few hundredths of a millimetre larger or smaller than the calculated dimensions. What is required is an engagement of a wheel and pinion that will produce a smooth and uniform lead throughout the engagement of each pinion leaf. Only when this is accomplished can the pitch diameters be presumed to be in constant velocity ratio. They will be defined by the point of contact of the tooth and leaf at the line of pitch centres.

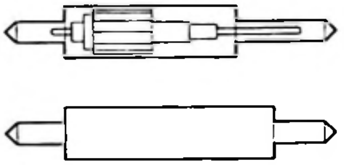
There are occasions when the pitch centres must be fixed. In these circumstances there is no alternative but to experiment with the diameters until the required conditions are achieved at the fixed dimension.

Pinions do not have an actual addendum. The lead is provided by the tooth addendum acting on the flank of the leaf. The tip of the leaf usually terminates in a semi-circular rounding to relieve any sharp edges. For pinions of fewer than 10 leaves it is the modern practice to extend the curvature to assist in the inevitable engagement before the centre line. Fig **198** shows the manner in which the curvature is increased. It can be seen that the curve increases in length as the number of leaves decreases. The leaf width reduces at the pitch circle but the full diameter does not change. The width of the leaves at the pitch circle is also dependent on the number of leaves, pinions of 10 and more having thicker leaves. Only the pitch circle diameter and the module are constant and the manufacturer's factor for the height of the addendum should be applied. If this is not available a factor of $1.5 \times M$ will give a full diameter sufficiently generous to allow for final polishing. Pinions should not be allowed to become undersized in finishing. Oversized pinions can be depthed to a better action.

If a pinion of 10 leaves and 2 mm pitch diameter is required then:

$$\frac{2}{10} = M \text{ and } (10 + 1.5) \times M \text{ equals the full diameter}$$

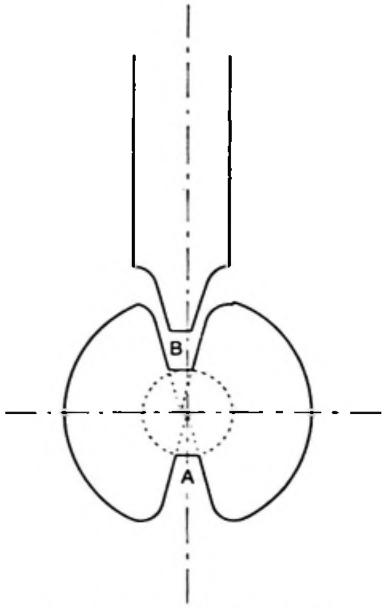
Turn the blank to the required diameter and leave the diameter for the leaves three times the length finally required. This will ensure rigidity and prevent warping when hardening. The length of the end arbors will depend upon the final dimensions of the finished pinion and the method of holding during the cutting, as in Fig **246**.



246 Pinion blanks

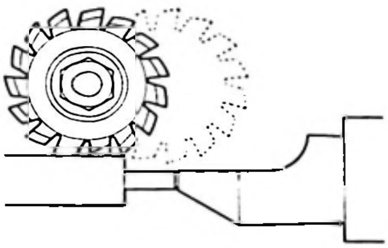
Pinions are most conveniently formed either in a pinion machine, especially adapted to the work, or in the lathe. Whichever machine is used rigidity is essential for smooth cutting requiring the minimum amount of final polishing. Pinion machines are intended for quantity production but are easily adapted to making single pinions. In addition to the forming cutter the spindles have provision for a slitting cutter to remove the bulk of the unwanted metal between the leaves of the pinions. The spindle is automatically shifted to engage the forming cutter after the slitting cuts are completed. Indexing is also automatic so that, once correctly set, the machine will produce uniform pinions without special attention. The blanks are held between centres. The indexing centre has serrations to grip the pinion point and the sliding centre is spring loaded to hold the blank firmly against the serrations. The great merit of these machines is their rigidity which results in a smooth cut, free of any chatter marks.

Considerable force is required to form the leaves of a pinion with a single pass of the forming cutter. This can result in deformation of the leaves especially during the final cut when the adjacent leaves are unsupported. It is for this reason that the slitting cutter is used in quantity production. For the making of a single pinion the slitting cutter is not essential because the forming cutter can be lowered during two or three passes until the full depth of cut is reached. It will be necessary to disconnect the spindle shaft cam if the slitting cutter is not used. The final depth of cut can then be controlled by the forming cutter depth screw and the slitting cutter screw used to lower the spindle after each pass. The cutter must be very sharp and kept lubricated with cutting oil to keep it cool and preserve the edge. A dull cutter will leave a series of indentations along the length of the cut.

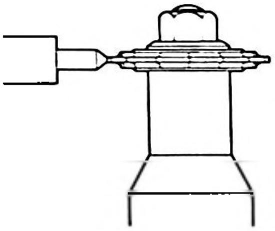


247 Incorrect cutter setting

It is essential that the cutter be set exactly above the axis of the blank. No practical tolerance can be allowed. The smallest error will show at *B*, in Fig **247**, as a deviation of the flanks from the radial. The smaller the pinion the greater will be the visual effect. The cutter is best set by disconnecting the automatic indexing and making trial cuts in a test blank. Examine each trial cut with a glass and adjust the cutter accordingly until it is truly above the axis of the blank and cutting to the correct depth. When correctly set the curve of the tip of the leaf will merge cleanly into the periphery of



248 Tailstock centre for pinions



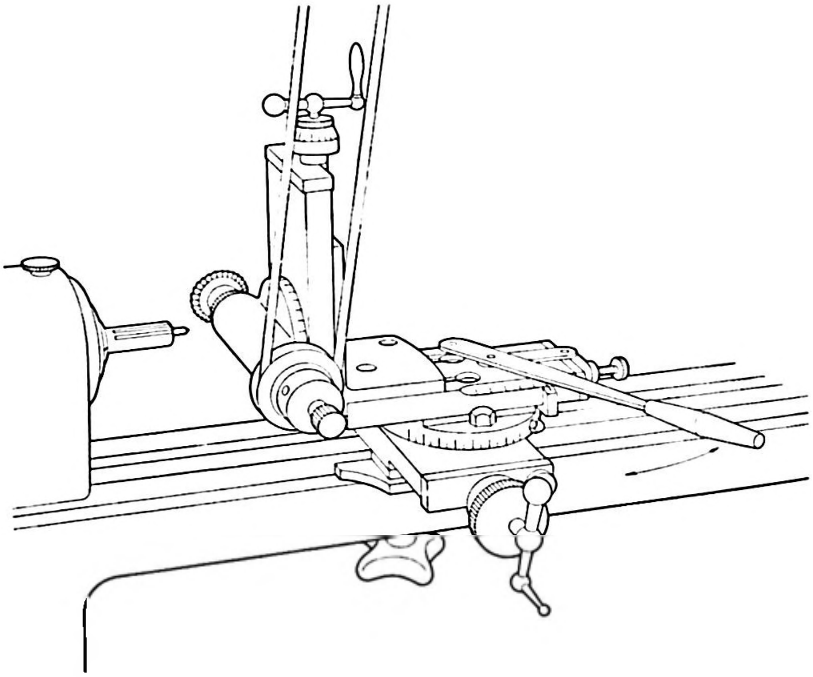
250 Aligning the cutter

the blank as seen at *A*, in Fig 247. When satisfied that all is correct reconnect the index and cut the final pinion.

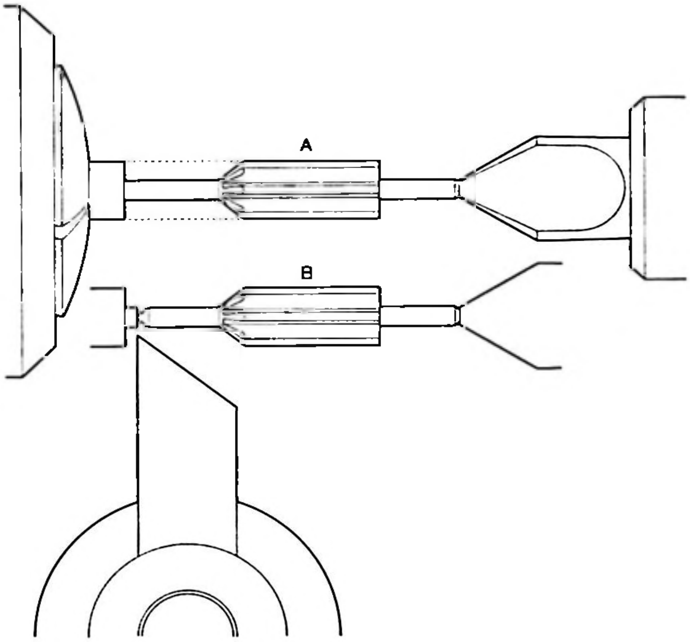
Setting the machine accurately to cut a true pinion requires great care and some expenditure of time. Once it is set it is a simple matter to make further identical pinions. If an extra half-dozen pinions are cut for each setting of the machine a stock can be built up and much repetitive work saved in the future.

The blanks for subsequent pinions do not need such careful preparation as the test blanks to which the cutter was set by reference to the full diameter. An increase in diameter of up to 5 per cent can be allowed for subsequent blanks which can therefore be made more easily and quickly by a single setting of the lathe cutting tool.

If small pinions are to be cut in the lathe a special tailstock centre, illustrated in Fig 248, will need to be made to enable the cutter to be lowered close to the axis of the blank. A large pinion can be cut from a rod held in a collet without a tailstock centre. A dividing plate must be fitted to the headstock. Turn the rod to the required full diameter with a slide rest. Note the final reading of the screw thimble for later reference and replace the slide rest with the milling quill set up as in Fig 249. Align the cutter with the point of the blank by taking the point into the space between two teeth of the cutter, as in Fig 250. When correctly centred raise the cutter above the blank and advance it to the limit of the required cut. Set the stop to avoid further advancement which could damage the cutter by contact with the collet.



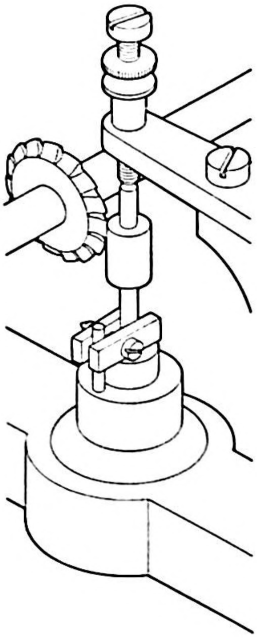
249 Milling quill with overhead drive for pinion cutting



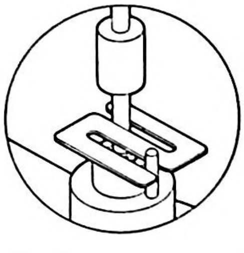
251 Parting off the finished pinion

Make the first pass with the cutter and index the blank after each pass. Bring the cutter down to the required full depth in two further passes and note the reading of the screw thimble of the vertical slide. Remove the milling slide rest and vertical slide completely and replace the slide rest. Turn away the excess pinion as at *A* in Fig 251 and part off as at *B*. Note that the back of the tool has been used for the parting cuts to avoid moving the tool and nullifying the thimble reading for the blank diameter. Examine the pinion with a glass. If the work has been carefully done there should be no errors of alignment. Errors of depth can occur with very small pinions when the milling attachment sometimes partly obscures full sight of the blank. This will show as turning marks at the tips of the leaves if the cutter has not been lowered far enough. The correction can be made by reference to the thimble reading of the vertical slide screw. If all is well the rod can be withdrawn sufficiently to turn a fresh blank for another pinion. The noted thimble reading for the slide-rest screw will facilitate rapid turning of the blank without need of measurement. It is a good plan to advance the thimble reading relative to the screw by 0.02 mm to ensure that all subsequent blanks are full in diameter. The sharpness of the cutter will be preserved if the speed of rotation is kept to about 500 rpm for 5 mm of feed per second.

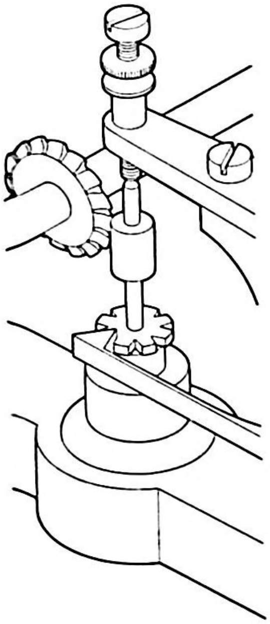
Pinions can be cut in the wheel engine if centres are fitted to the dividing plate spindle and the gallows clamp. A carrier fitted to the pinion blank will serve to turn it with the dividing plate. Figs 252 and 253 show the arrangement. Note that the carrier must be sprung or clamped on to the driving pin to eliminate backlash. If the plate is not suitably divided for some pinions there is usually a sufficient amount of undivided surface to make the necessary



252 Pinion clamp carrier



253 Pinion spring carrier

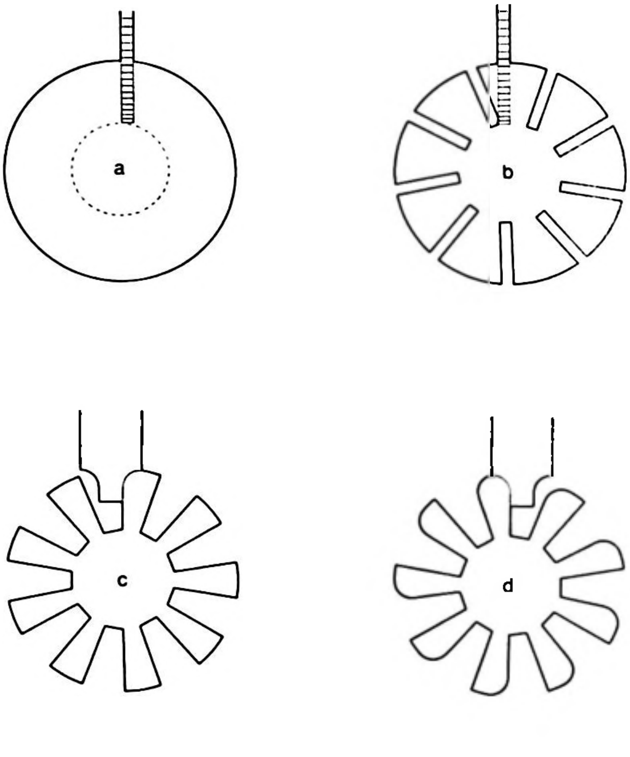


254 Pinion dividing disc

divisions. Scribe a circle with the point of the indexing arm and divide this into the appropriate number of equal angles with a dividing compass. Where the compass marks cross the circle, drill holes to take the point of the index. If the division is done carefully on a large circle any errors will be too small to affect the division of the pinion. At one time pinions were divided by fitting a notched disc to the arbor and indexing directly, as in Fig 254.

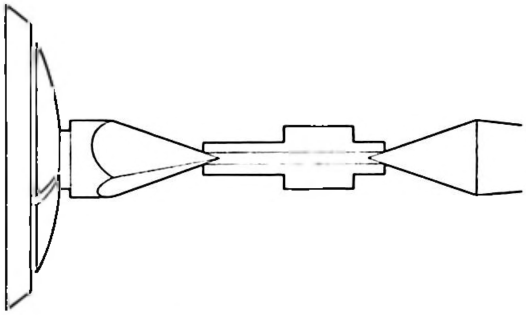
The following method of forming the leaves may be useful in an emergency. It was used for making a pinion of 9 leaves for a Breguet chronometer when no cutter was available. A division of 9 was made on a plate, as described earlier, and fitted to the headstock mandrel of the lathe. The blank was turned to diameter and machined with a slitting saw and a wheel-tooth cutter, as illustrated in Fig 255, *a*, *b*, *c*, and *d*. The finished pinion was entirely satisfactory and has enabled the chronometer to continue its life's work of extolling the virtues of the illustrious Breguet.

Hollow pinions are drilled through before the leaves are cut. Make the blank a little oversized to allow for possible eccentricity of the hole. Make a sink in the end with a graver and drill the hole to half-depth. Reverse the blank and complete the drilling from the other end. Smooth the hole with a broach as the blank is rotated in the lathe. Lubricate the broach copiously with thin oil and withdraw frequently to clear the swarf.



255 Forming a pinion from available cutters

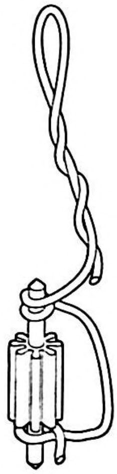
Make a driving centre of the form shown in Fig 256 to fit a collet of the lathe or the taper of the pinion engine. Hold the blank between the driving centre and the tailstock centre. Before clamping the tailstock give the base a light tap to drive the pinion blank on to the square drive of the headstock centre.



256 Driving centre for hollow pinions

Hardening and Polishing

Harden the pinion by heating to a glowing red and plunging vertically into oil. Hold it in stiff, iron, binding wire, as shown in Fig 257. It is not necessary to bind it completely in fine wire. Note that the pinion is in no way constrained by the wire but is free to turn in the loops. The wire passing down to form the lower loop is well clear of the leaves to ensure even distribution of the heat. Cover the pinion with good-quality soap. Coarse soap will sometimes etch the surface as impurities burn in the flame. Slowly rotate the wire as the temperature is raised. When the pinion glows evenly overall drop the wire vertically into the oil. Scrub the pinion vigorously with a stiff brush and benzine to remove the oil and burnt soap. The surface will now be white in colour. Roll the pinion on a brass plate over the spirit lamp and temper to a medium-blue colour. If the characteristics of the metal are not known the heat treatment should be experimented with before tempering the pinions. The metal should turn easily with a sharp graver to expose a bright surface. If the surface is dull after turning, the metal is probably too soft. There is no virtue in leaving the pinion too hard for it will be difficult to work and may fracture when the wheel is riveted in position. If, on the other hand, it is too soft it will distort during the riveting and the finished pivots will bend easily.

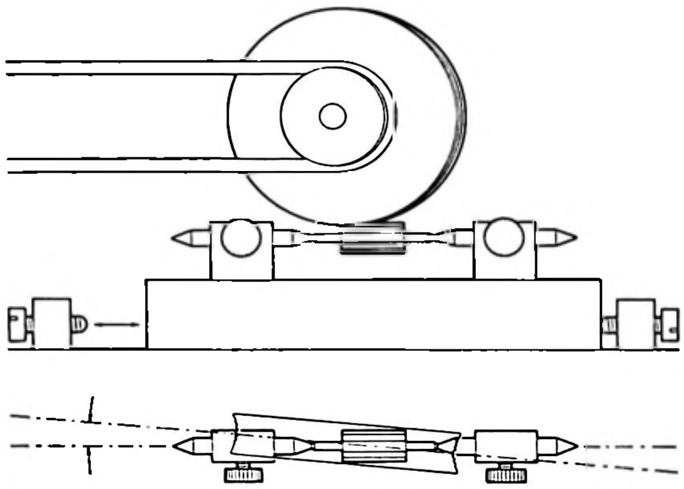


257 Iron-wire holder for pinions

The leaves of the pinion are polished with a disc of close-grained softwood. Pear wood is suitable. The disc is fitted to a spindle with a pulley for the drive. The pinion is rotated in centres below the disc at a little less than 90° to its axis. When the spinning disc is lowered into contact with the sharp end of the pinion leaves the pinion will rotate and cut a thread into the wood. The angle of the thread will be determined by the inclination of the pinion axis to the disc spindle. This should be kept small to prevent excessively fast rotation of the pinion which would cause the tips to polish more quickly than the flanks. During the polishing the pinion is moved axially to and fro to polish the whole length of the leaves.

The principle of construction is shown in Fig 258. Charge the disc with a wet paste of fine polishing compound. For a wheel of 50 mm diameter about 250 rpm would be a satisfactory speed. Set the pinion slide stops to allow the wheel to reach the end of the leaves without falling below the root diameter. Excessive contact with the ends of the pinion will damage the thread and deform the pinion. Keep the disc wet with a mixture of paraffin and oil. The pinion should have a muddy-grey appearance during the polishing. If it is bright in appearance while in contact with the revolving disc it will merely gloss without removing the cutter marks.

The disc will last longer and wear more evenly if made from segments glued together to show only end-grain at the periphery. When properly prepared the polishing action is very fast and care must be taken not to reduce the diameter of the pinion unduly.



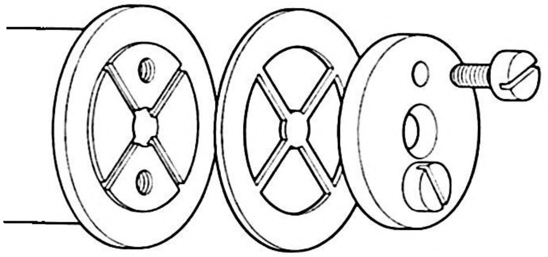
258 Pinion polishing machine

Escape Wheels

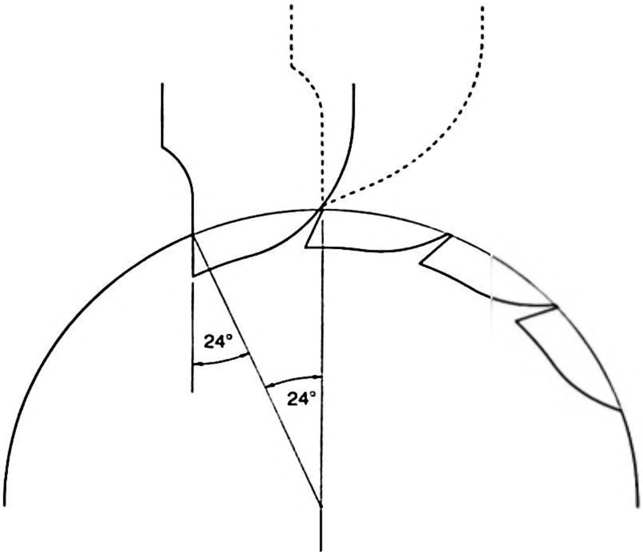
The blanks for brass escape wheels can be prepared and mounted for cutting in the same way as the blanks for train wheels. Finish the spokes and inner rim completely before fitting the blank to the holder, as in Fig 259. Note the brass washer fitted behind the blank to support the teeth against the cutter pressure.

Ratchet-toothed wheels can be cut with fly cutters. When made exactly to shape one cutter only is required. Fig 260 shows a chronometer wheel cut with a single fly cutter. The 24° rake of the face of the tooth is obtained by setting the cutter to the centre line and scribing a line on the blank at the face of the cutter. Turn the blank through 24° (or the required angle of rake) and reset the face of the cutter against the end of the line.

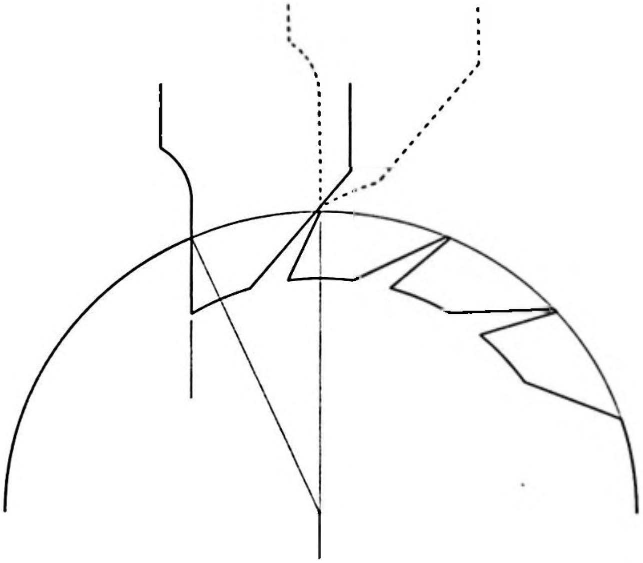
Make the first cut with the cutter set shallow. Turn the blank through one tooth space and make the second cut. Turn the blank backwards to the first cut and pass the cutter through the gap, lowering it a little at a time until the required tooth-tip width is



259 Chuck for escape-wheel blanks



260 Single fly cutter for chronometer wheel

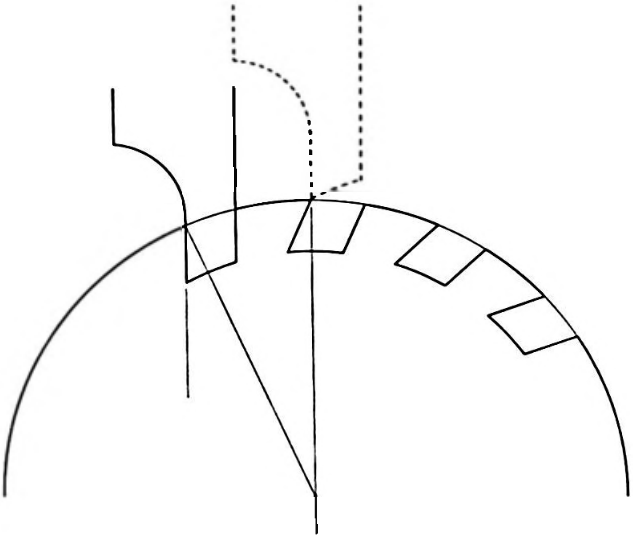


261 Single fly cutter for ratchet-toothed wheel

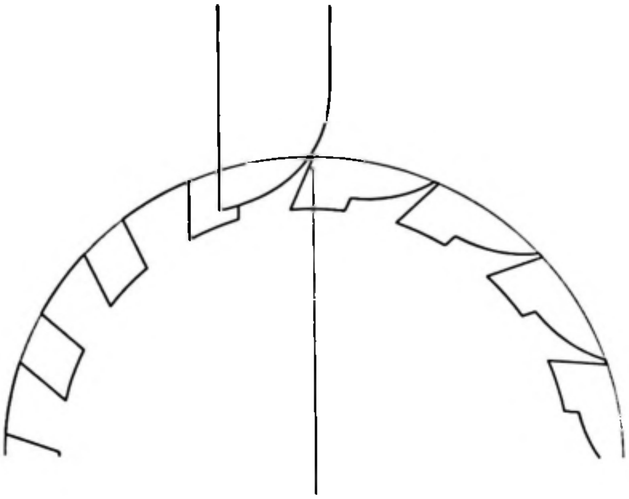
reached. The teeth can now be cut in one pass each. With a well-prepared cutter no further finish is required to the teeth after cutting. English ratchet-toothed wheels can be cut in the same way, as in Fig **261**.

English chronometer wheels need two cutters to form the teeth. The faces of the teeth are cut first with the blank set up as in Fig **262**. The backs are curved with a second cutter which is lowered a little at each pass until the tips of the teeth are the required width, as in Fig **263**.

For a pocket chronometer wheel of 9 mm diameter the tip of the tooth would be half a degree in width or about 0.04 mm. For smaller wheels this can be reduced to about 0.03 mm and for lever escape wheels may be reduced further to 0.02 mm.



262 First cutter for English chronometer wheel



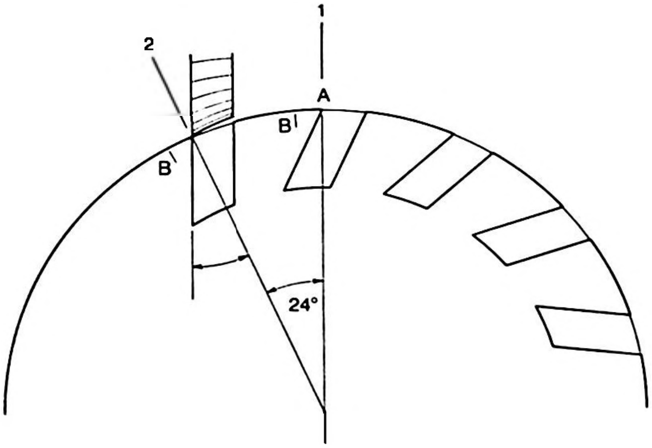
263 Second cutter for English chronometer whe

Divided-Lift Wheels

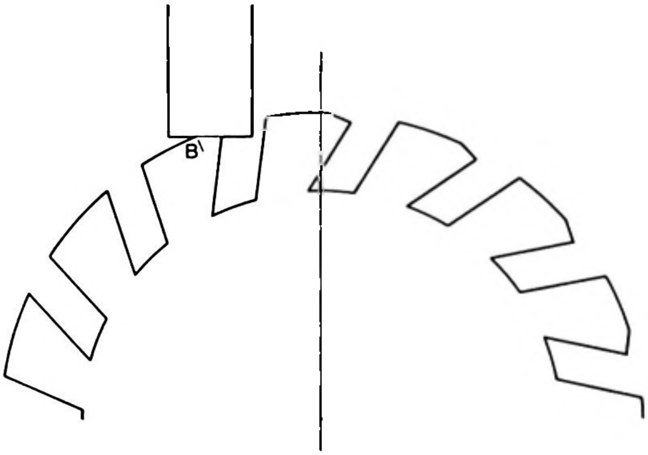
Three cutters are needed for making divided-lift wheels. Fly cutters can be used for brass wheels. Multi-toothed cutters are necessary for steel wheels. Steel wheels can be thinner and lighter than brass wheels. They can be polished easily to a very high finish and offer greater resistance to wear and damage by abrasion.

Fit the blank into the holder, Fig 259, and turn true and to the final diameter. If required turn the oil bevel to the underside of the edge. Make a true centre with a rigid point in the tailstock and drill the centre hole. Set the slide-rest cutter to the centre height and make a mark, *A*, at the edge, as in Fig 264. Turn the headstock by an angle equal to the width of the impulse incline and make a second mark, *B*, as in Fig 264. Turn the mark *A* to the top vertical at position 1 minus the 24° of the angle of the locking face of the tooth at position 2. Set the cutter as at position 2 in Fig 264 and make the first cut. Repeat the cut for the required number of teeth.

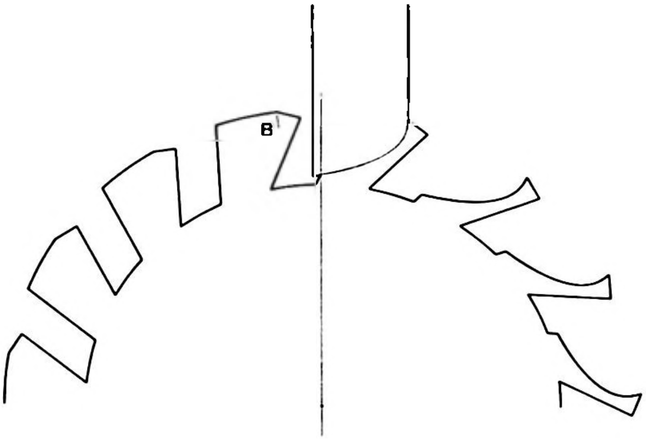
Turn the headstock to reset the wheel from the starting mark, position 2, by the number of degrees equal to the angle of the lifting incline, in this case 5°. Make the second series of cuts to meet the tip of line *B*, as shown in Fig 265. With the third cutter complete the



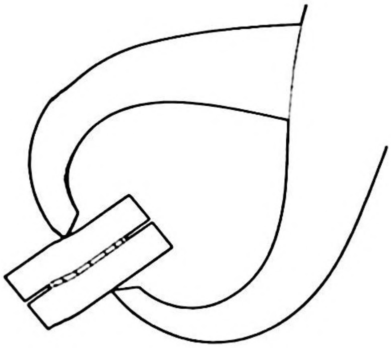
264 First cutter for club-toothed wheel



265 Second cutter for club-toothed wheel



266 Third cutter for club-toothed wheel

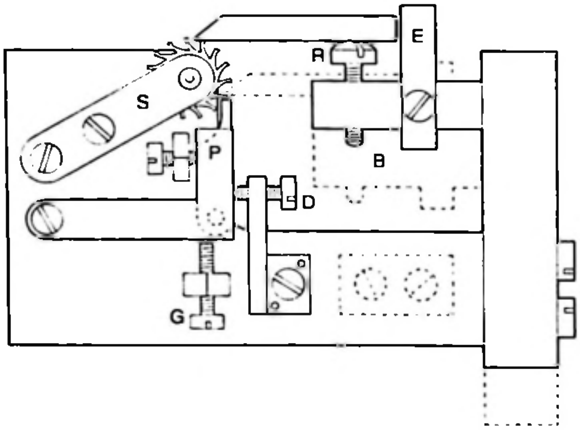


267 Hardening discs for escape wheel

curve of the first cut to meet the toe of the incline at mark *B* in Fig 266. By following this sequence of cuts the alignment of the cutter can be precisely observed and the angles correctly produced.

If the wheel is required to be hardened it must be enclosed in a thin-walled box and separated from contact with loose iron wire or clamped flat between steel discs, as in Fig 267. Raise to bright-red heat and drop edgeways into water.

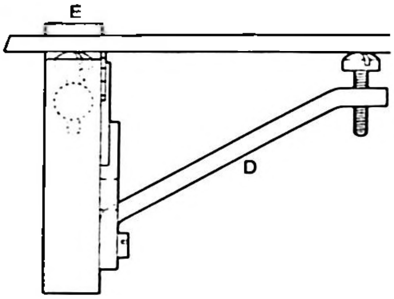
Flatten the underside with a fine stone and temper to blue. Finish all edges with iron polishers and oilstone paste. Grain or polish the upper surface as required and polish the inclines and locking faces. The tool illustrated in Fig 268 will hold the polisher at a fixed angle for each successive tooth. The wheel is pivoted on a pin and clamped to the frame by the spring *S*. The screw *R* is adjustable to bring the polisher level with the face to be polished, while screw *G* is adjusted to hold the wheel at the required angle. The rest *P* can be pivoted aside to turn the wheel without disturbing screw *G*. If necessary rest *P* can be locked with stop *D*. The dashed outline of



268 Polishing tool for escape-wheel teeth bracket *B* shows the position for polishing the locking faces of the teeth.

Start the polishing with a freshly prepared burnisher to relieve the sharp corners that would scrape the paste from the polisher. Finish with diamantine on bell metal or free-cutting brass. The action of the polisher will produce a slight curve to the surface. This is beneficial because it reduces the surface contact with the pallet stones.

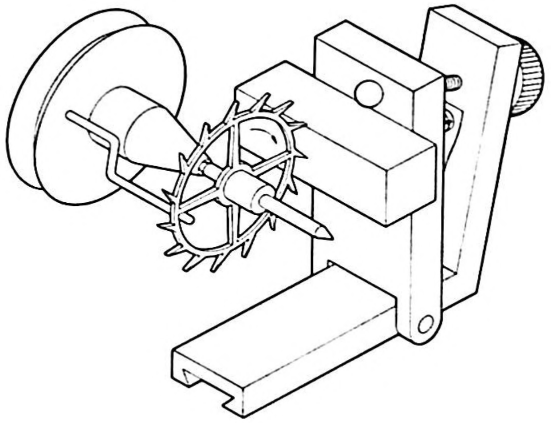
When it is necessary to polish the surfaces flat the additional bracket *D*, in Fig 269, will support the polisher at a constant level. With this in use the polisher will rest on three points and require only a light downward pressure from the pad of the forefinger. Utilized in this way the stop *E* is useful for preventing the polisher sliding sideways off the tooth.



269 Polisher rest for escape-wheel polishing tool

Topping Escape-Wheel Teeth
Cutter burrs at the fine tips of chronometer escape wheels can be dressed while the wheel is revolved on its pivots with a bow in the dead centres of the turns. In Fig 270 the stone is fixed to a bracket held against an adjusting screw by a spring.

Bring the stone into contact as the wheel revolves in its correct direction of rotation. On the return stroke of the bow, spring the runner away from the stone to prevent contact that could turn a burr on to the impulse face.



270 Escape-wheel topping tool

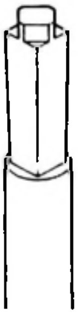
6

MAKING SMALL COMPONENTS

Square Holes

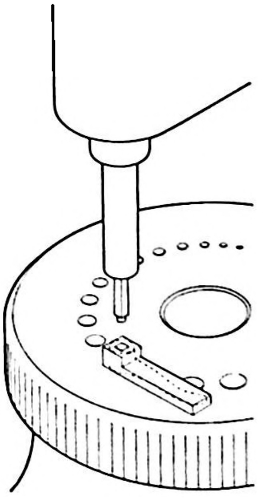
When coupling two components by a square fit, it is better to make the shaft by gradually reducing it to fit the square hole. When the hole is to be made to fit the shaft, measure the shaft at each end of its length. If the flats are not equal make a sketch so that the exact shape of the square can be visualized.

Make the broach from wire that will fit one of the punches in the staking tool. Turn the diameter to equal the greatest diagonal of the square shaft. File the shaft square with a small negative taper using a filing rest, as in Fig 275. Finish the shape to correspond with the shape of the shaft. If the shape is tapered the square of the broach must equal the small end of the taper. Finish the broach so that it is 0.02 mm smaller than the shaft to be fitted and make a mark to ensure correct orientation of the square. Relieve the lead corners to form a guide in the hole to be broached. Harden in oil and the broach, as it appears in Fig 271, is ready for use.



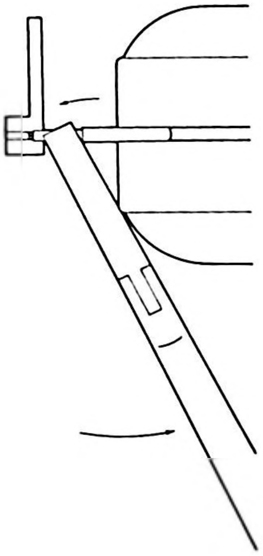
271 Broach for square holes

Shape the blank for the component to be broached so that it will resist deformation under hammer blows. A ratchet wheel for example is a simple piece and will withstand the pressure. It should, however, be made thicker than will be finally required to allow for chipping at the corners on the underside. Chipping can be avoided by gradually opening the hole with increasingly larger broaches. If only a very few holes are to be broached it is simpler to clean up the component after a single broaching.



272 Broaching the hole

For a long square in a pipe, such as the piece shown in dashed outline in Fig 272, a large block is initially required to prevent collapsing. Drill the hole equal in diameter to the largest width across the flats. Start the broach in the hole with two or three blows to enter to a depth approximately equal to the distance across its flats. Mark the orientation of the broach. Remove it and pass the drill through the hole to clear the broaching chips. The broach will be tight in the hole, but risk of breakage will be avoided if it is gripped in the vice and the work levered off with pliers, as in Fig 273. Fit up again with the broach correctly orientated and drive further in. Repeat the process until the broach passes through the hole. Made in this way the hole will have smooth walls and there will be very little chipping of the exit corners. Reducing it to its final length will remove any chipping. Finally drive the square shaft to be fitted into the hole almost up to the shoulder. Only very light taps will be required to stretch the hole by 0.02 mm, the 'undersize' allowed in the broach. After hardening and tempering the component will be a perfect, light, friction fit to the shaft and will not rock in any direction.



273 Levering off the component

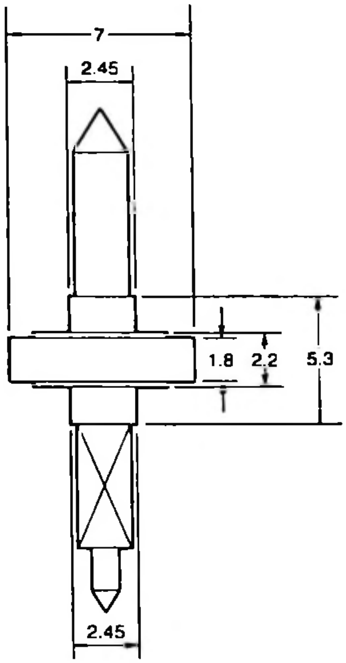
Barrel Arbors

Turn the arbor from oil-hardening steel and leave the radial dimensions a little oversized for final turning and polishing after hardening. The axial dimensions must be correct before hardening if any squares are to be made.

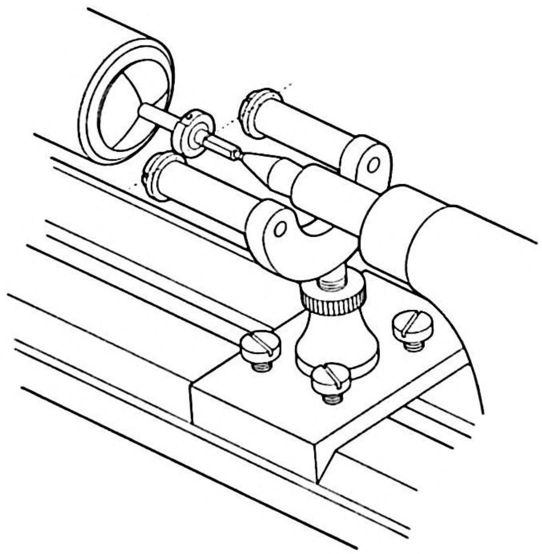
The dimensions of an arbor suitable for the barrel of the watch illustrated in Plate IV are shown in Fig 274. Note that the hook is a steel pin in a hole drilled at an angle to draw the spring close to the arbor. File the snailed step after drilling to erase any scuff marks from a wandering drill point. When drilling an angled hole start the drilling radially and then turn the work to the required angle to complete the hole.

The arbors are left long in order to help with the final finishing between centres. It is important that all the radii of the completed arbor are concentric. An error of eccentricity of 0.01 mm will cause the barrel to wobble by 0.1 mm and this is half the available running clearance. Thus the clearance on one radius of the barrel will be one-third the clearance at the opposite radius. This is unacceptable; the barrel must be quite upright both on its arbor and in the frame.

To make the square use the double roller filing rest, set up as in Fig 275. Note the roller flanges carefully positioned to guide the file.



274 Dimensions of barrel arbor



275 Double roller rest for filing square arbors

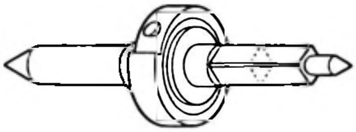
It is advisable to give the square a very slight positive taper by tipping the rollers with the adjusting screws in the base. The taper is just sufficient to avoid any possibility of a negative taper which would allow the fitted component to slacken when pressed fully home. This will be seen only when the square is completed, as in Fig 276. Note the reduced end-diameter for gripping in the lathe collet or running in centres.

Adjust the height of the rollers so that a No. 3 cut, flat file will rock on the arbor above the rollers. File each flat until the rollers prevent the file rocking. If a component is to be fitted to the square try the fit after each reduction. When the component begins to fit the end of the taper change to a No. 6 cut, smoothing file.

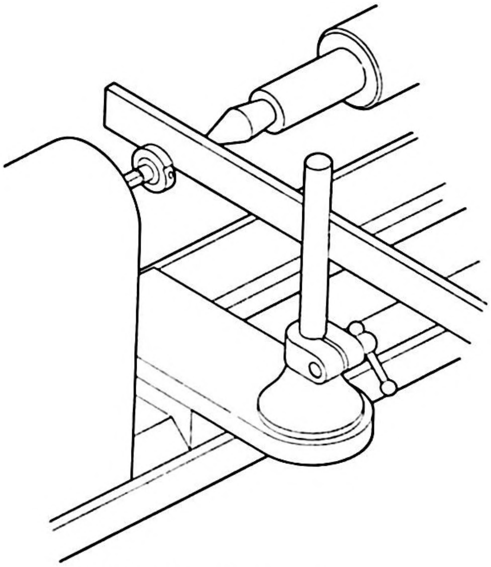
Try the component end for end on the square arbor and adjust the taper as required. Leave the fit just short of the shoulder of the square so that the final cleaning with oilstone paste after hardening will complete the fitting. To avoid a false fit, the corners of the square must be relieved with a fine, flat file before each trial fit.

The finished square is shown in Fig 276. Note the relieved corners and the length of the square. It is difficult to make a short square accurately to fit a component. The square will eventually be reduced in length in the manner indicated by the dashed lines. During the course of initial fitting of the mainspring and stop work to the barrel, the long square will be useful for holding in the pin vice.

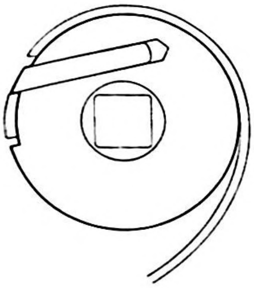
Fit the arbor into a loop of stiff iron wire, as shown in Fig 257, and harden in oil. Temper to suit the material so that the arbor can be cut with a sharp graver. The dimensions, which were left 0.05 mm oversized, can now be reduced almost to size between centres and finished with oilstone paste at the square and hub. Polish the pivots and their shoulders with diamantine. These large shoulders can be polished with the lapping tool. If this is not available fit a post into the 'T' rest holder, as shown in Fig 277. Adjust the position so that a



276 Barrel arbor ready for completion



277 Polishing the barrel arbor pivots



278 Detail of the hook

broad polisher can be held square with the pivot and face while guided by the post.

Make the pin for the hook from steel tempered to pale blue. Drive it firmly into the hole and cut to length, as shown in Fig 278, with the mainspring hooked in position. Note that the snail of the arbor and length of the hook assure a smooth surface for the coils to wrap around without distortion.

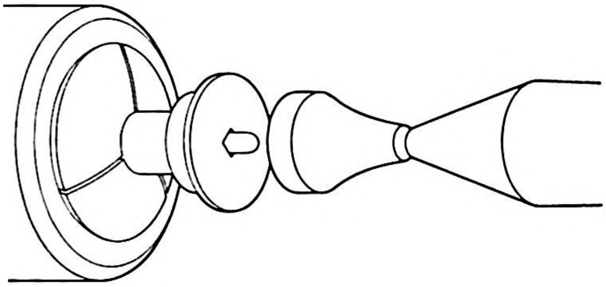
Fit the arbor to the barrel by opening the holes with a smooth broach. This must be kept quite upright to the barrel face to avoid distortion of the holes. The upright can be observed by fitting a cork to the broach. Turn the face of the cork true with the broach and keep this face parallel to the work surface. Lubricate the broach with oil to prevent the surface of the brass tearing. Turn the broach while advancing and withdrawing it in a single motion to prevent seizure in the hole. When the pivot begins to enter the hole continue the broaching from the other side. Broach alternate sides until the pivot fully enters the hole up to the shoulder. Open the hole in the cover by the same means.

The arbor should now fit into the barrel with the cover on and without end clearance. This is introduced by a facing cut to the inner bosses with the barrel or cover in the step chuck in the lathe. Allow only 0.05 mm clearance and check this with the cover snapped into position.

Ratchet Wheels

Preferably the wheel is made from a steel blank. If this is not available one can be made by parting a section from a bar and facing it to the correct thickness or by cutting it from a sheet of steel. In either case make the disc larger in diameter than will finally be needed.

Fit the disc into a step chuck in the lathe and drill the centre hole. Broach the hole square. Fit to a turned peg on a flat face in the lathe and clamp under the tailstock centre, as in Fig 279. Turn to diameter and cut the teeth. Drill any other holes required and harden in oil.



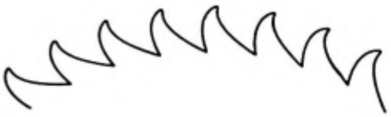
279 Mounting the ratchet wheel in the lathe

Before tempering place the wheel on a cork surface with a locating pin at the centre. Hold the cork in the vice and grind the wheel flat with a coarse oilstone. This will also remove the burrs raised by the tooth cutter. Finally temper to a medium blue and finish as required.

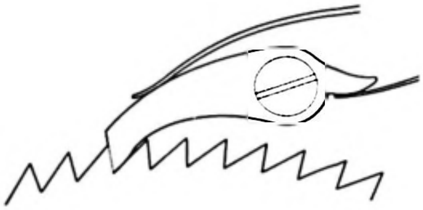
The shape of the teeth of a ratchet or winding wheel may sometimes be a matter of individual preference. There are times when simple, triangular teeth are all that is required. The watch illustrated in Plate IV employs these teeth although they are also used for transmission to the second barrel.

The so-called wolf's teeth, shown in Fig 280, were invented by Lepine and were popular with Swiss watchmakers in the nineteenth century. They give an illusion of smoother transmission with increased strength. They are a nice conceit but in fact offer no advantage. The pawl must be carefully pitched so that the arc of its tip does not intersect the curve of the tooth. If the curve of the tooth is too long the pawl may rest on the curve when the stop work engages fully wound. If this happens it will fly out of engagement when the winding is completed.

Teeth of cycloidal form are now usually used for ratchet wheels. Like wolf-tooth wheels they are more secure with a recoil pawl.



280 Wolf-tooth winding wheel



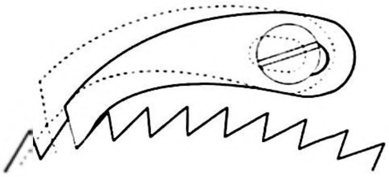
281 Simple ratchet pawl

Pawls

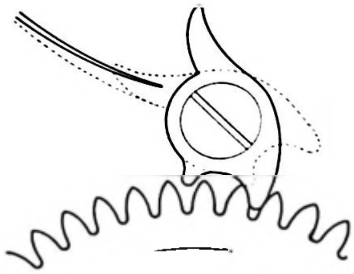
The simplest form of pawl is shown in Fig 281. It is for use with ratchet teeth. The spring may press down towards the wheel or up under a tail away from the wheel.

If the barrel is without stop work then some form of resilient or recoiling pawl is necessary to relieve the pressure of the fully wound spring. Fig 282 shows an elongated hole which will allow the pawl to recoil upon engagement.

A better arrangement is shown in Fig 283 in which the pawl will allow the ratchet wheel to turn back some 15°, which is sufficient to relieve the extra pressure of the mainspring hook when fully wound without stop work. With this form it is not necessary for the return spring to be in contact when the pawl is engaged.



282 Recoil ratchet pawl



283 Involute recoil pawl

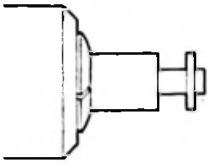
Stop Work

The form of stop work to be used in a watch under construction is a matter of choice. The Geneva stop work is the most compact and the simplest to make when properly designed. It is extremely reliable and works without friction.

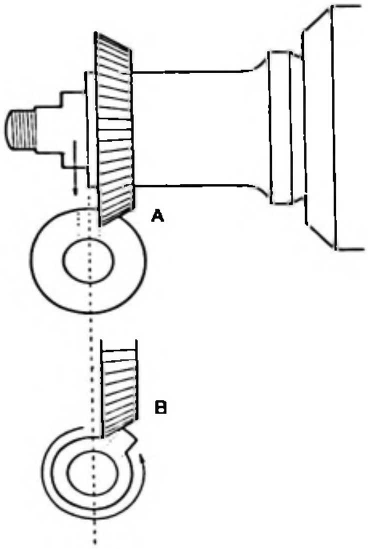
It can be made in the lathe from steel rod. Stop work of suitable size for the *tourbillon* illustrated in Plate IV would be machined from rod of 7 mm diameter. Make a drawing twenty times actual size and take the dimensions from the drawing.

Stop Finger

Part the rod partially to leave a disc of about 0.9 mm thickness, as in Fig 284. Make a mark at the centre with the point of the graver and set the milling cutter to one side of the mark by half the width that the finger will be. Pass the cutter into the disc to the depth of the base circle of the fingerpiece, as in Fig 285 at *A*. While the cutter continues to rotate turn the headstock slowly by hand to cut away

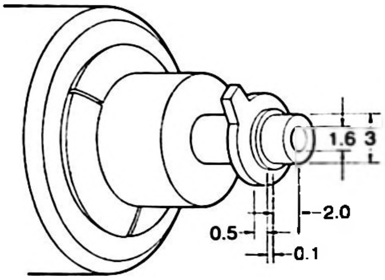


284 Stop finger disc



285 Machining the stop finger

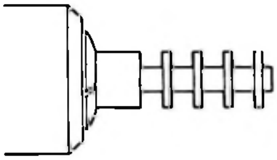
the surplus metal, as in Fig 285 at *B*. Drill a hole of the required size for the square at the centre. Turn the pipe to the form shown in Fig 286. This will be the lower plate pivot and will be squared on to the barrel arbor. Part off the disc which is now ready for hand finishing.



286 Geneva stop work fingerpiece

Once the cutters are set and the thimble readings noted it is a simple matter to repeat the operation to make the second fingerpiece and perhaps more for future use.

Make the square hole. File away the metal close into the root of the finger to a shape that will pass freely through the slots of the star wheel. The side clearance at the root of the finger will allow the points of the star-wheel slots to pass without touching. The clearance must be kept to a minimum to avoid jamming as the corner passes into the hollow.

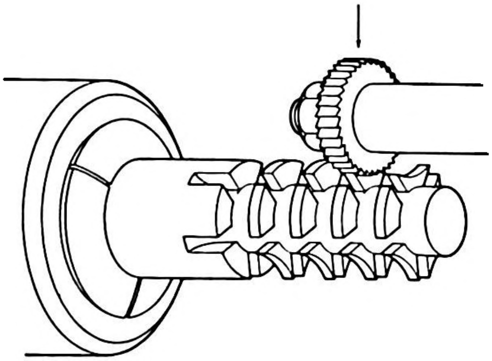


287 Geneva stop work star-wheel discs

Star Wheel

Similar methods are used to make the star wheel. Turn the discs by parting the rod partially, as in Fig 287. Note the boss of the first disc. This diameter is taken from the drawing and indicates the depth to which the finger slots will be cut.

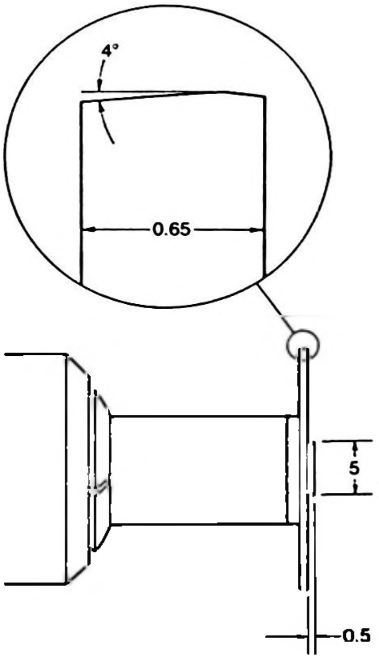
With a slitting cutter in the quill of the vertical slide, index the rod to cut five longitudinal slots. If a cutter is available the locking hollows can also be machined, as in Fig 288. Turn away the depth-



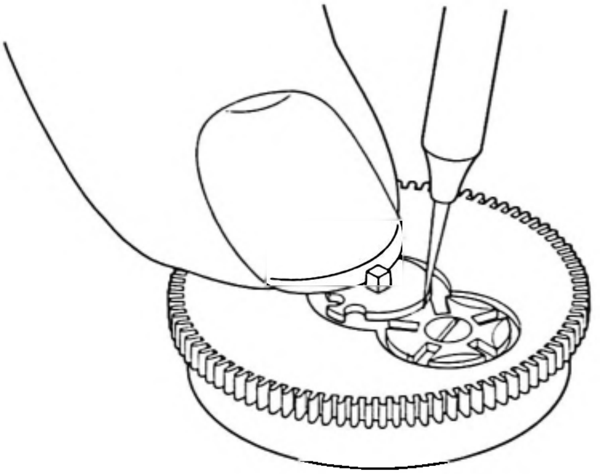
288 Cutting the slots and hollows

guide boss and drill the hole at the centre. Turn the recess for the screw head. Part off and the star wheel is ready for hardening and hand finishing. When only a very few star wheels are required the hollows can be filed with a half-round file.

Fit the star wheel to its recess in the barrel. Hold the finished fingerpiece down with the thumbnail and scribe the arc for the base circle with a sharp point, as in Fig 289. File away the surplus metal so that the fingerpiece fits closely into each hollow.



290 Turning the barrel cover



289 Scribing the depth of the hollow

Harden in oil and temper to a deep blue. The star wheel must be hard enough to resist deformation of the locking sector by the corner of the stop-finger base circle. Finish all edges and the screw-head recess with a fine grain surface. Grain or polish the flat surfaces as required.

Barrels and Covers

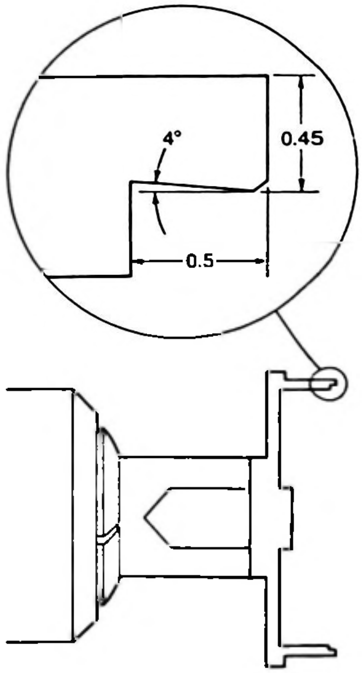
When a sufficiently large lathe is available a large barrel can be made from a bar and completely finished before parting off. Where a smaller lathe is to be used the barrels can be made from discs.

Covers

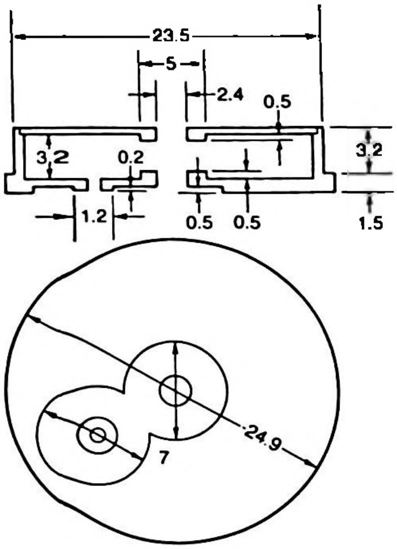
The barrel covers should be made first from discs. Solder the disc to a post of sufficient length to hold in the lathe. Turn on all surfaces to the form shown in Fig 290. The turned disc can now be detached and washed with soap and hot water to dissolve any flux. It is ready to be fitted to the barrel and will be finished later.

Barrels

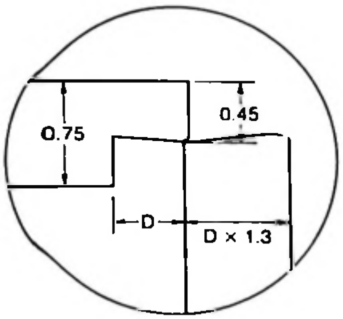
Solder a disc for the barrel to a post in the lathe and turn all surfaces to the form shown in Fig 291. Dimensions for a barrel of 24.9 mm diameter, and suitable for the watch illustrated in Plate IV, are



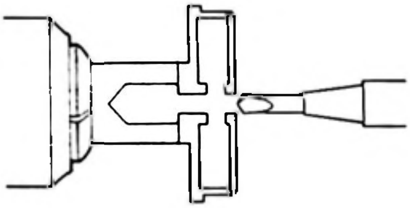
291 Turning the barrel



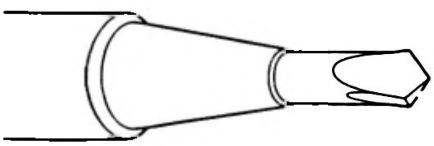
292 *Tourbillon* barrel dimensions



293 Barrel-cover snap details



294 Drilling the barrel holes



295 Barrel drill

given in Figs **292** and **293**. Cut the teeth using the method shown in Figs **234** and **235**.

Turn the snap groove to fit the edge of the cover, as shown in Fig **293**. The extra thickness in the cover will ensure a tight, snap fit in the barrel groove. Turn the cover over and snap into the groove. Drill through cover and barrel with the stiff drill especially made and which is shown in Figs **294** and **295**. This will ensure that the holes are exactly aligned and will avoid the necessity of boring. Finally face off the cover flush with the lip of the barrel. This final cut needs a sharp tool with a slow feed to avoid pressure that could distort the flat of the cover.

Detach the barrel from the turning post and push out the cover with a piece of wood passed through the hole from the underside. File the notch at the edge to assist future removal. Wash the barrel with soap and water. Hold the barrel in a step chuck and face off the underside. Turn the recess for the stop-work finger. Fit the barrel into the mandrel plate and make the recess for the star wheel. Note that these recesses are 0.5 mm deep but the shoulder for the star-wheel screw is 0.3 mm high, leaving 0.2 mm depth of screw head in the star wheel.

Balance Rollers

Chronometer Impulse

Chronometer impulse rollers are made from carbon-steel rod. Turn the rod in the lathe to the required full diameter. Centre with the graver and drill the hole. Part from the rod leaving the disc 0.1 mm thicker than finally required. Rest the disc on cork and make both sides flat with an oilstone slip. Rotate through 90° at regular intervals to maintain an even thickness. Mark one side with a chamfering point. Grip the disc in a collet in the lathe with the mark showing and make true with the tailstock runner, as in Fig **384**.

Broach the hole to size with the roller rotating and the broach stationary and aligned by the tailstock. The hole will now be slightly larger at the marked side, which will be the upper side fitted against the balance hub.

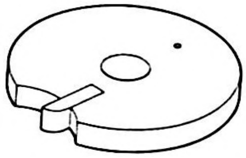
Cut the slot for the impulse pallet with a saw in the headstock of the lathe. The acting side of the pallet stone should be radial to keep impulse friction to a minimum. Note that the impulse face is reversed for a *tourbillon*. Put the roller in the vice of the vertical slide and set it to the correct height. Set the edge of the roller in contact with the face of the saw and, by advancing it in the required direction by half its diameter, bring the saw face to the radial. For irregularly shaped pieces the saw face can be set to the radial by using the square corner of a ruler as a guide, as shown in Fig **302**.

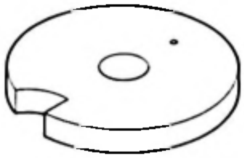
If the pallet stone is ready-made, cut a slot in waste material to check the thickness of the cutter. The slot in the roller must be the same depth as the length of the stone plus the necessary clearance for the escape-wheel teeth. To avoid weakening the roller at the centre the length of the slot should not exceed two-thirds the radius of the roller. File the crescent to give clearance to the escape-wheel teeth and the roller is ready for hardening.

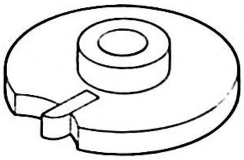
If the roller is to be unjewelled, cut a shorter slot and file away one side only. Fig 296 shows the tooth clearance for a jewelled roller and Fig 297 for an unjewelled roller. Unjewelled rollers might be thought inferior to jewelled rollers but in fact they work just as well and with a brass wheel show no sign of wear after many years of continuous use.

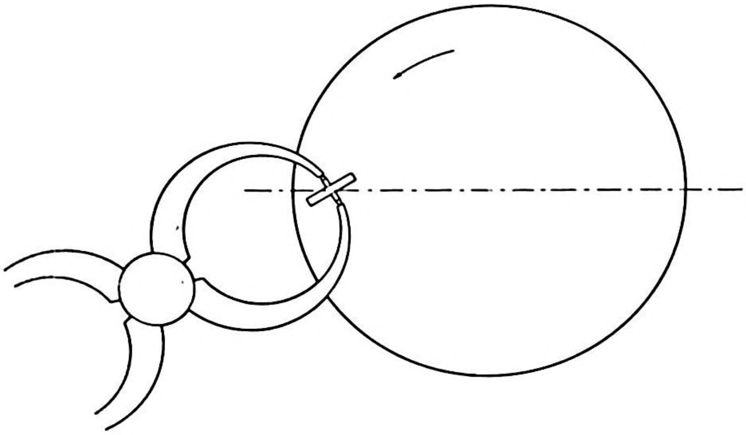
Harden the roller in oil and temper the jewelled roller to a deep blue. The unjewelled roller must be hard at the impulse surface. Fit it to a tapered brass wire held in the flame. The centre will temper earlier than the edge and can be stopped when the edge turns a pale-yellow colour. The unjewelled roller can be harder at the centre without risk of splitting if fitted tightly to the staff. If there is room beneath the balance-staff hub, the roller can be machined to leave a collar at the centre to add strength, as in Fig 298.

The roller can be polished or grained to preference. The edges of chronometer rollers are usually polished but this is not really necessary. They can be polished on a turned post in the lathe or on a tapered arbor in the turns. Hold the polisher lightly in contact beneath the roller's edge so that the contact can be seen. Finish on a wood lap with diamantine. The tapered arbor can be held in the callipers to allow the roller to spin. Hold the roller in contact with the lap at an angle to produce both rotating and polishing action, as in Fig 299.


296 Jewelled chronometer roller

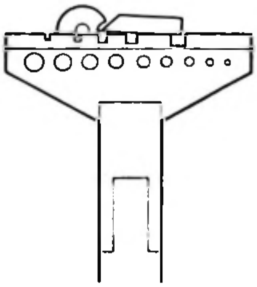

297 Unjewelled chronometer roller

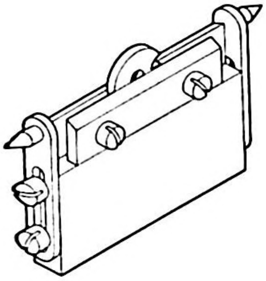

298 Chronometer roller with collar


299 Polishing the edge of the roller

While the edges are being polished, the corners of the crescent for the tooth clearance and the corner of the impulse face of the unjewelled roller will become rounded. These can be sharpened by polishing the crescent with a shaped, iron polisher and the impulse face with a flat polisher.

Locate the polisher for the impulse face in a notch of the hand vice, as in Fig 300. This will prevent it sliding over the end of the face. Use short strokes with light pressure to prevent the handle rising or falling. The slight cross-sectional curvature of the surface, which will result from free-hand polishing, will reduce the surface contact of the tooth and this will do no harm.


300 Polishing the impulse face



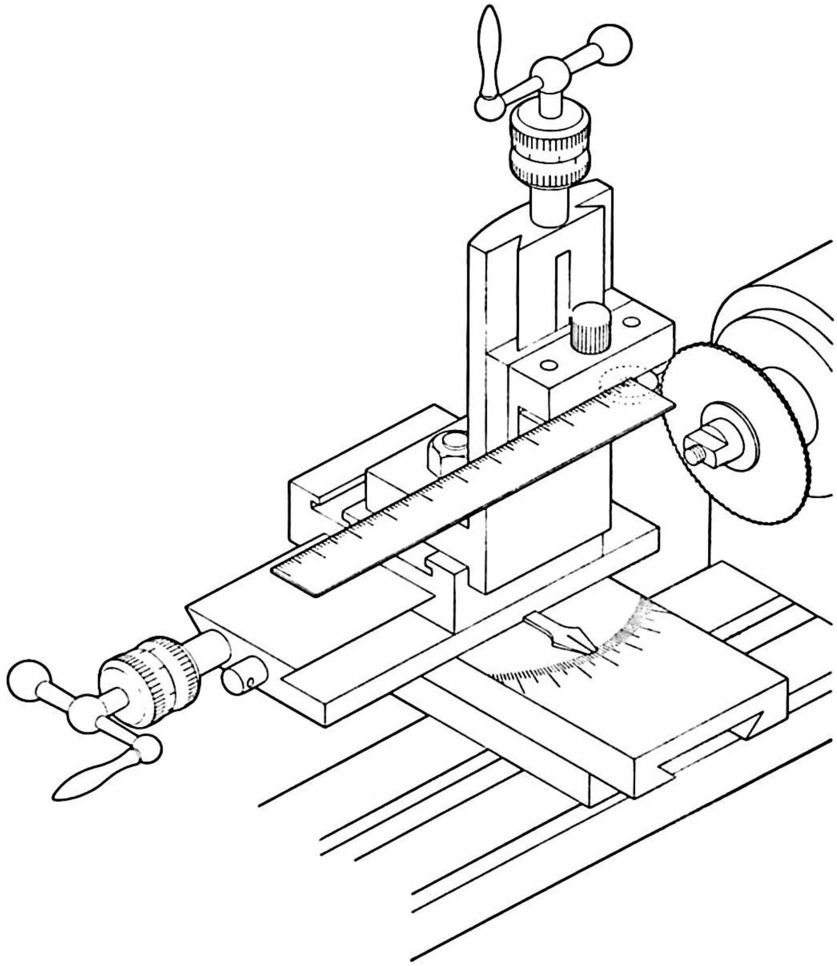
301 Swing tool for polishing flat surfaces

If a flat surface is preferred it can be polished in a swing tool, as in Fig 301. This is a clamp to hold the work in position for polishing. It has a pivot at each side adjustable to bring the surface to be polished level with the points which are pivoted in the turns. Keep a firm pressure on the polisher and polish with slow, short strokes.

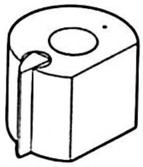
Chronometer Unlocking Roller

Turn the roller from carbon-steel rod in the lathe. Centre with the graver and drill the hole. Taper the hole and mark the upper surface with a chamfer to indicate the large end.

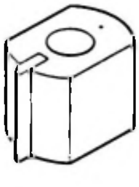
The jewel can be fitted into a slot cut in the lathe, as in Fig 302. For a small roller an axial drilling, opened at the edge, will make a more secure fitting for the jewel. Drill the hole and reduce the diameter of the roller until the hole breaks through. The rollers with jewels fitted are shown in Figs 303 and 304. Note that for a *tourbillon* the unlocking face of the stone is reversed but must be radial. The roller will need at least one flat to assist in turning it on the staff when adjusting the escapement.



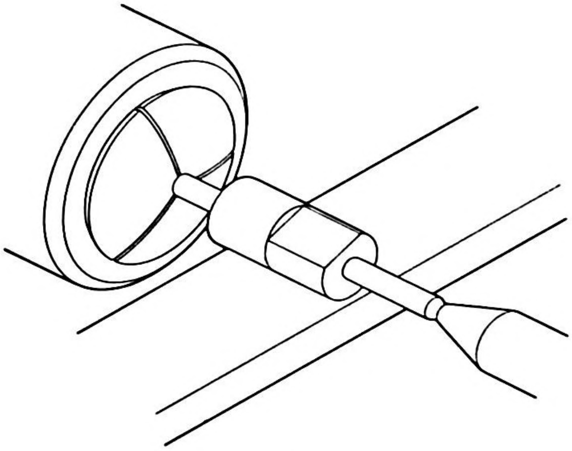
302 Cutting a slot in the lathe



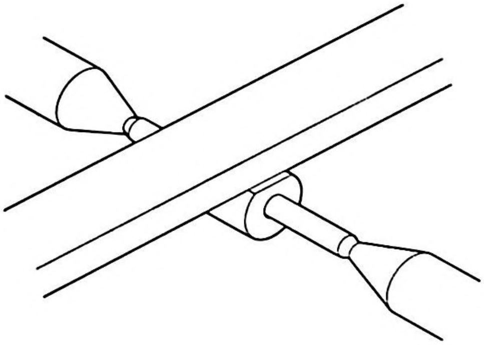
303 Unlocking jewel in axial drilling



304 Unlocking jewel in axial slot



305 Polishing the safety roller



306 Polishing the flat

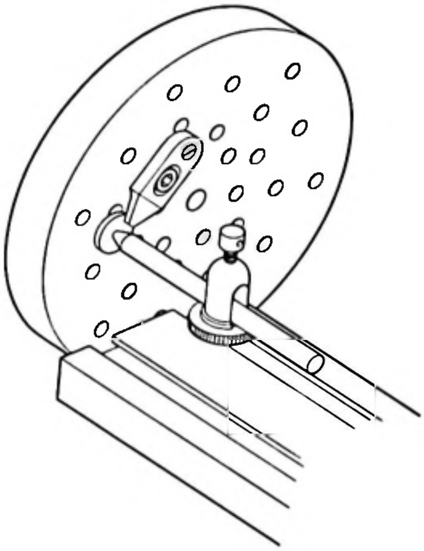
Polish the roller on a tapered arbor as for the impulse roller. It will be necessary to support the polisher with a second roller to mask the flat surfaces, as in Fig 305. To polish the flats, thread the roller loosely on to an arbor in the lathe with the tailstock centred to keep it in position. Alternatively fit it to a tapered arbor pivoted between centres. Use the polisher above the surface, as in Fig 306.

Independent Double Chronometer

The impulse roller of the escapement illustrated in Fig 482 requires precise positioning of the slots for the two impulse pallets. The drop of the wheel tooth on to the pallet, after unlocking, is affected by the position of the unlocking pin. This is also true of the conventional chronometer but the angle of unlocking and the angle of drop of the tooth can be adjusted by twisting the rollers on the balance staff. With the double chronometer the angles are fixed in the design of the escapement.

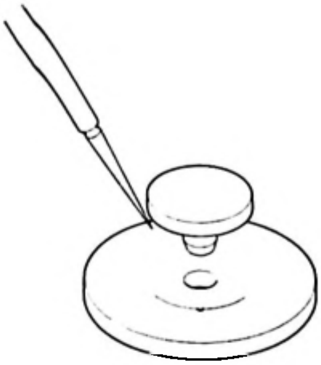
Make the roller in the form of a disc with radius equal to the radius of the impulse pallet. The dimensions can be taken from a drawing of the escapement made twenty times actual size. Drill the centre hole and make tapered. Identify the upper surface with a chamfer mark. Drill the hole for the unlocking stone. The radius for the hole is taken from the drawing. It must be accurately found on the roller. The lever angle is very small and a misplaced pin will either fail to disengage the horn of the lever or fail to catch the corner of the notch correctly when approaching to unlock.

If a jig-borer or pointing machine is available the hole can be marked and drilled with ease. Alternatively the position can be marked with a point in the slide rest of the lathe. Make a point of steel to fit the tool clamp of the slide rest, as in Fig 307. With the point in the centre hole, hold the disc so that it cannot move against the face plate of the lathe. Secure it with a single clamp. Take up the back-lash of the cross-slide thread and set the thimble to any whole unit. Withdraw the point with the longitudinal slide screw. With the cross-slide screw, reset the position of the point to the required radius of the pin and bring into contact with the disc. A light tap with a hammer on the end of the rod will take up the backlash in the slide and mark the position for drilling.



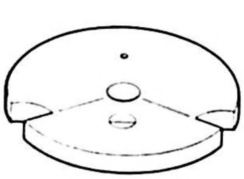
307 Marking centre distances in the lathe

If there is no means of measuring off the distance accurately the position can be found by making a stud to fit the centre hole and a flange radius which is equal to the radius of the centre for the pin, as in Fig 308. Measure the flange with the micrometer. Make the pin a close fit in the roller hole. Scribe a line at the edge with a sharp point to reach into the corner. Make a chamfer on the line and drill the hole.



308 Marking centre distances with a guide stud

Fit the pin to the roller as described on page 160. Fit the roller to a temporary staff and try the action. Turn the roller to unlock the escape wheel. At the border, make a scratch to mark the position of the tooth as it falls on to the edge of the roller. Make a similar mark for the drop point of the second wheel. File a notch at each mark with a radial flank for the impulse surface, as in Fig 309.



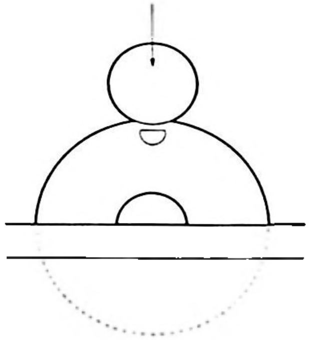
309 Marking the impulse faces for double chronometer

Check the action of the wheel teeth on the impulse faces. They must drop safely on to the face. This can be checked by reversing the motion of the balance when the tooth has dropped. Allow 5° of reversed motion to set the tooth off the impulse face on to the edge of the roller. Cut the slots for the stones using the method described for the chronometer roller.

Lever Rollers

The single roller for the lever escapement is made from a disc parted from a rod of steel in the lathe. Turn the rod to diameter and make the centre drilling.

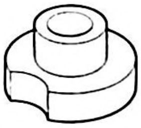
Drill the hole for the impulse pin to the measured diameter of the pin. File a steel pin to the same shape and dimensions. Harden and temper to purple. With this pin in the impulse pin hole, hammer the front of the hole to close on to the pin and form the crescent for the guard pin. Grip the roller in the soft jaws of the vice and use a piece of blued-steel wire to shape the crescent, as in Fig 310. When these rollers were popular a special tool was available to form the hollow but the method described will suit the occasional roller very well.



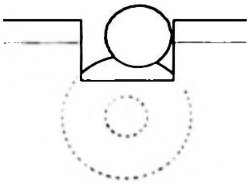
310 Forming the crescent of the single roller

Safety Roller

For a two-piece English roller the safety roller is easily made from wire turned to diameter and drilled through in the lathe. Taper the hole as described for the chronometer rollers. It is not necessary to mark the large side for this will be formed as a spacing tube to separate the upper and lower rollers, as in Fig 311. Form the crescent by filing and, after hardening, polish the safety edge. To avoid accidentally scratching the safety roller's surface during filing start with the roller in a notch of the hand vice and rest the file in the corner. When the crescent is established the roller can be made more visible for completion, as in Fig 312.

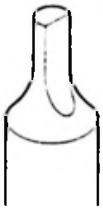


311 English safety roller



312 Establishing the crescent

The same methods of broaching and drilling are used for making the one-piece double roller, but the crescent must be machined. Grip the large roller in the lathe collet and make the crescent with a cutter in the quill of the vertical slide. The single-bladed cutter of the type used in the pantograph will cut cleanly and quickly. Cut the crescent with several passes axial to the roller. The alignment of the crescent with the impulse pin is critical. Examine carefully after each pass and correct as necessary before the final pass.

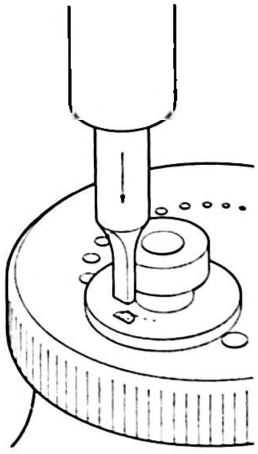


313 Broach for impulse pin

Double Roller Impulse Pin

Swiss double rollers are made in one piece. English rollers are generally made in two pieces.

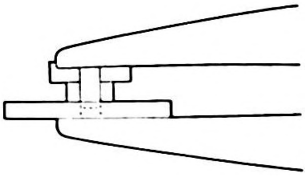
The hole for the ruby impulse pin must be made with a D-shaped broach, as in Fig 313. Turn the wire for the broach to the diameter of the impulse pin and with a very little taper. File the flat to the measured dimensions of the pin minus 0.02 mm. Note that the broach must be very stiff and short and with a shank to fit a punch of the staking tool. Fit up the staking tool with the broach above a hole in the table, as in Fig 314. Use the smallest possible hole in the table and check the alignment of the broach before placing the roller in position. The radius of the pin can be accurately fixed with the punch located against the oversized flange of the safety roller, which can later be reduced to size.



314 Broaching the pin hole

Tap gently until the tip of the broach passes through. The corners at the upper side will be chipped but this is easily rectified if the roller blank is left overthick.

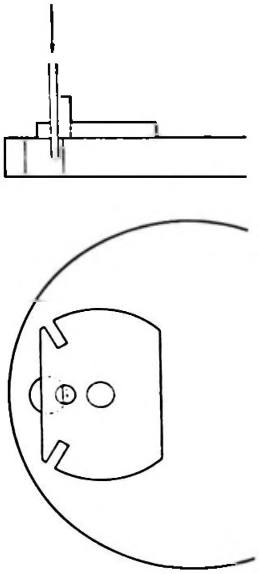
Try the impulse pin at the hole. If the broaching stops immediately the hole is formed it will be too small. Tap the broach in further until the pin can enter tightly. Hold the pin in the brass tweezers. When it will stand in the entrance to the hole grip the roller and pin together, as shown in Fig **315**, and press the pin fully home. Fitted in this way the pin will need very little shellac to secure it after the roller is hardened and tempered. If the roller is made of brass the pin can remain a press-fit and will need no shellac.



315 Fitting the pin

A half-round pin is most securely fitted when wedged with a brass plug. The round drilling can be precisely located. This is very important for the escapement of the double impulse chronometer illustrated in Fig **482**. For this the pin must be located to allow the impulse to start at precisely the right moment in both directions.

Drill the hole a little undersized and open with a cutting broach to fit the pin. File a brass taper with a flat. Rest the roller on a stake so that the pin is supported, as in Fig **316**. Put in the plug and press lightly to fill the half-hole. Cut off flush with the end of the ruby pin. Clean off the cutter marks and press home flush with the surface of the roller.



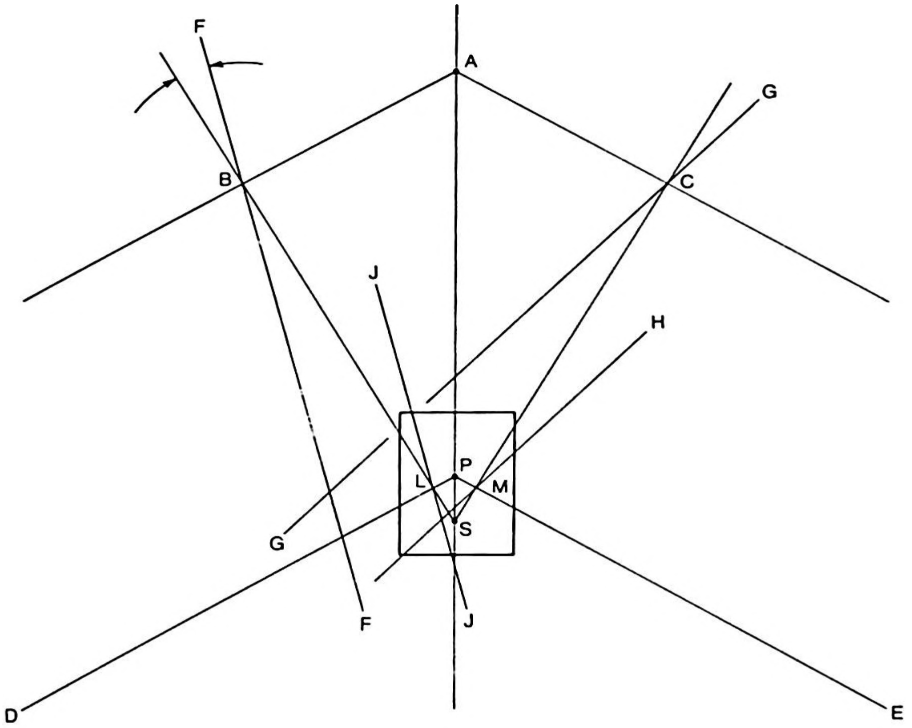
316 Securing the pin with a brass plug

The edge of the hole in the stake will prevent the pin moving as the plug is pressed home. Cut off the surplus on the underside and clean off the cutter marks with a stone. Fitted in this way the pin cannot possibly move but can be easily withdrawn.

Levers and Pallet Frames

Lever Escapement

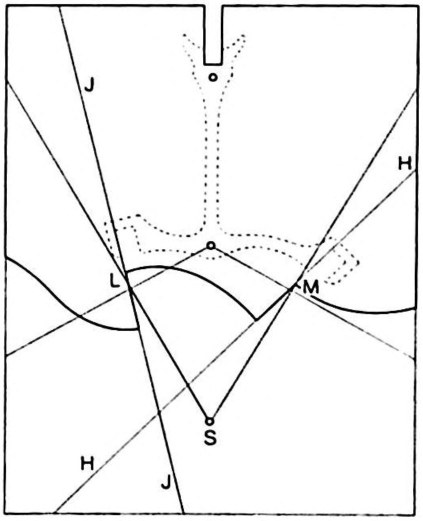
Prepare a piece of carbon steel by smoothing one surface. Colour by heating to a dark blue so that the lines to be scribed will show clearly, as in Fig **317**. Scribe first the centre line and drill the hole *P* of 0.5 mm diameter for the pallet centre. From this hole mark the position for the escape-wheel centre and drill a second hole *S* of 0.5 mm diameter. Take the distance from a correct drawing made twenty times actual size. Place the prepared steel on a sheet of drawing cardboard. Mark round the edge, cut out the shape and press the steel into the hole level with the surface of the card. The angles for the lever can now be drawn to a large scale to avoid errors. With a sharp, hard pencil extend the centre line and mark the pallet centre *A* at a scale of 20:1. From *A* draw the locking angles of the pallets and mark their radii at *B* and *C*. Draw *DPE* parallel to *BAC* extending the lines to *P* with a fine, sharply pointed scriber. Draw *BSC*. The locking points *L* and *M* at actual size are at the intersection of *BSC* with *DPE*. Draw the lines *FF* and *GG* at the required angle of draw to the perpendiculars to *AB* and *AC* without marking the plate. Produce *MH* from exit locking point *M* and parallel to *GG*. Produce *LJ* from entry locking point *L* and parallel to *FF*. These lines are the locking faces of the pallets.



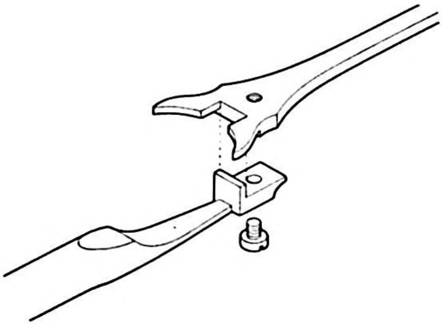
317 Marking out lever pallets

Cut away the surplus material, as shown in Fig **318**, leaving the extensions on *JJ* and *HH* below the locking points *L* and *M*. When cutting the slots rest the face of the saw lightly against the extensions and align the face with a straight edge, as in Fig **302**. This will ensure exact alignment with *JJ* and *HH* and prevent possible run-out of the saw causing a shift of points *L* and *M* or a wide cut.

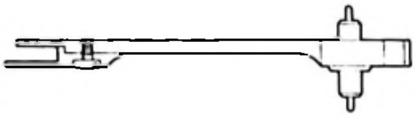
Finally cut the slot for the notch, drill the hole for the guard pin



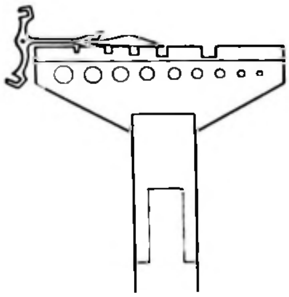
318 Slotting saw guides for lever pallets



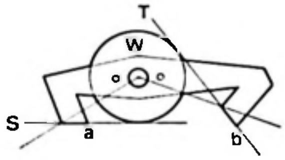
319 Fitting the safety dart



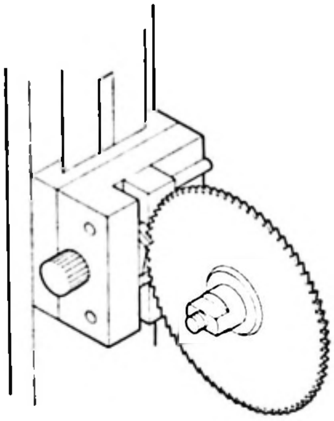
320 Profile of finished lever



321 Polishing the notch



322 Marking out English pallets



323 Cutting the jewel slots for English pallets

and file the pallets to shape. The guard pin is filed from wire, as in Fig **319**, and located by a tongue fitting the root of the notch.

Note that the lever can be reduced in thickness to reduce weight, and further reduced at the notch, as in Fig **320**. Harden the completed pallets in oil and temper to blue.

Polish the notch with a burnisher. Hold the horn of the lever in the hand vice and adjust the angle to bring the burnisher into full contact, as in Fig **321**. A few gentle strokes with a freshly prepared burnisher will produce a full polish with a slightly curved surface. Finish the edges and surfaces as required.

If the pallet staff is to be a press-fit it should be polished to within a 0.01 mm 'oversize' and fitted to a smooth, broached hole. Make the stones as described on page 188. The English pallets are filed up to the impulse inclines with the pallet stones set into the thickness of the steel. As shown in Fig **322**, turn a disc *W* to the diameter of the circle for the impulse tangents and pin to the pallet-staff centre. With a sharp point and a straight edge resting against disc *W* scribe the line *Sa* for the entry lift. Repeat for line *Tb* for the exit lift. When filing to shape check the drops in the depth tool and adjust the inclines for length at *a* and *b*.

Finally drill the lever pin holes and cut the slots for the stones. These need to be cut separately to ensure sufficient depth without cutting into the centre. Set the vice horizontally on the vertical slide with the slitting saw in the headstock. After cutting the first slot, tip the pallets in the vice and cut the second, as in Fig **323**. Cut and fit the stones as described on page 189. Harden and temper to pale blue.

Independent Double Escapement

Prepare the steel smooth on one side as for lever pallets. As shown in Fig **324**, drill the hole *S* for the staff on the centre line. Turn a disc to the radius of the lockings and pin to the pallet-staff hole. Scribe at its circumference the arcs *ABC* for the centres of the locking-pallet pins. Cut a hole in drawing card and let the steel into the hole level with the surface. Extend the centre line at an enlarged scale. Take the angle *GSF* from the escapement drawing. With a sharp point scribe the lines *SC* and *SB* on the steel. Drill the holes for the pins at the intersections of the arcs *ABC* with the radiating lines. Cut the slot for the notch and file the frame to shape. Harden in oil and temper to pale blue.

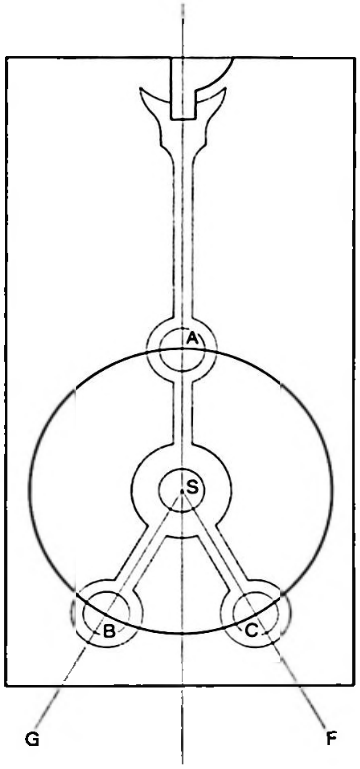
Co-Axial Double-Wheel Escapement

Prepare the steel as for lever pallets. As shown in Fig 325, drill the hole for the pallet staff *S*. Set the steel in drawing card level with the surface. Extend the centre line at an enlarged scale. Make separate discs of radii equal to the locking-pin centres and pin to the pallet-staff hole. Scribe the arcs *A* and *B* with a sharp point at the periphery of the discs. Take the angles *ESC* and *ESD* from the drawing of the escapement and scribe the lines to the pallet-hole centre. Drill the holes for the pins at the intersection of the arcs *A* and *B* with *C* and *D*.

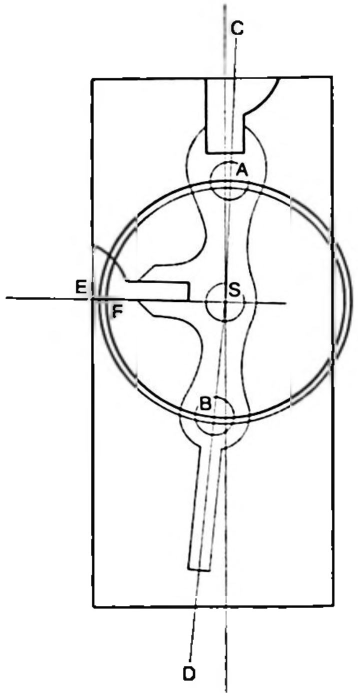
Line *ES* represents the impulse face of the lever pallet. File away the plate to leave the extension *F*. Rest the face of the saw against the extension to hold the saw to the line when cutting the slot. Cut the slot for the notch and file the frame to shape. Harden in oil and temper to pale blue.

Single-Wheel Escapement

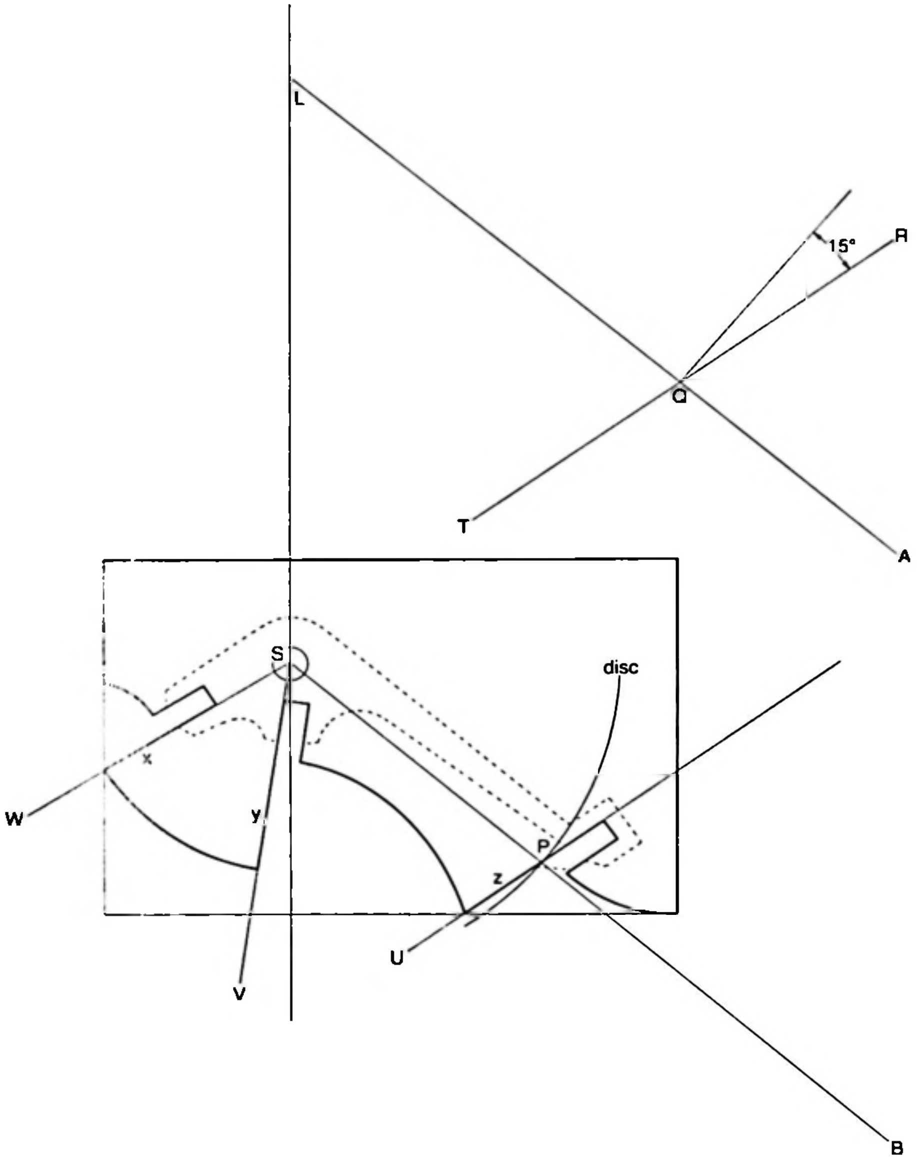
Prepare the steel as for lever pallets. As in Fig 326, drill the hole *S* and scribe a centre line *LS*. Let the steel into a sheet of drawing card level with the surface. Extend the centre line at an enlarged scale on the card. Take the angle *SLA* from the drawing and draw the parallel *SB*, extending this with a sharp point to the centre *S*. Mark the



324 Marking out independent double-wheel escapement pallets



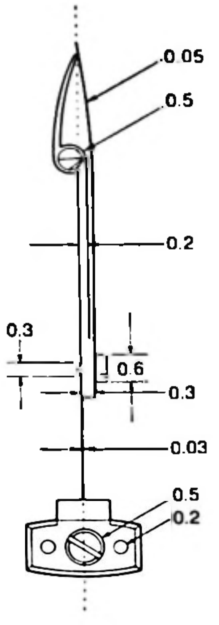
325 Marking out co-axial escapement pallets



326 Marking out pallets for single-wheel escapement

locking point *P* for the locking stone, if necessary, by scribing at the periphery of a disc turned to diameter and pinned at *S*. From the locking point *Q* on *LA* produce *TR* at the required angle of draw. Scribe *PU* parallel to *RT* and extend this across the plate.

From the drawing take the angles *BSV* and *VSW*. File up to the lines for the slots, leaving the extensions *x*, *y* and *z*. Rest the face of the saw against the extensions to hold the saw to the line when cutting the slot. File to shape and harden in oil. Temper to pale blue. The lever for this escapement is fitted above the pallets on the same axis.



327 Dimensions in mm for a pocket-watch detent

Chronometer Detents

Spring Detent

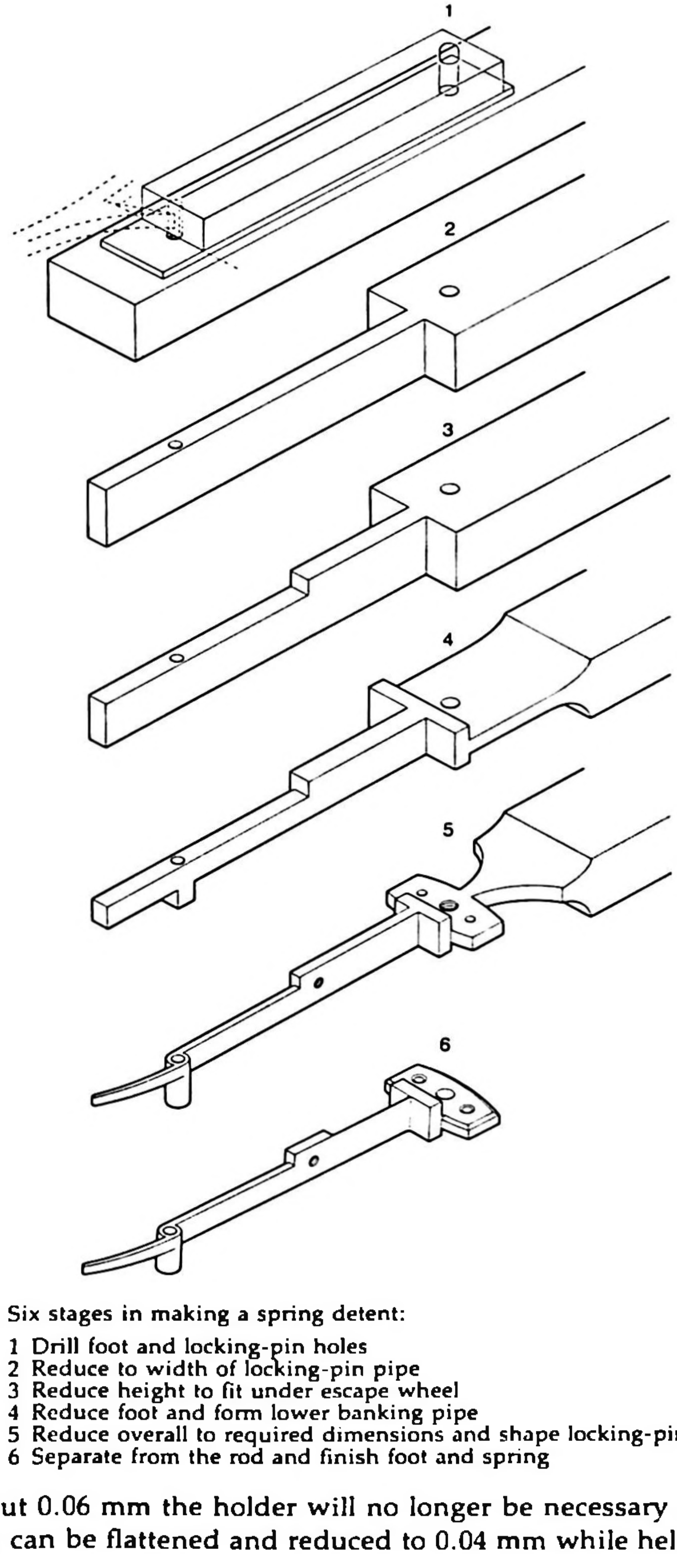
The detent is most conveniently filed from a square rod which can serve as a handle. Dimensions suitable for a pocket watch are given in Fig 327. The method of drilling through the jig plate for the centre distance of the drillings for the locking pin and foot screw for the *tourbillon* carriage, Fig 328, stage 1, is not appropriate for a conventional watch.

If the detent is a replacement, the foot hole in the plate will be ready drilled and the detent must be made to fit. For a new watch scribe a line from the balance centre to pass the locking tooth by half the diameter of the locking pin. Drill the foot hole on this line. File a flat, brass gauge to fit the frame level with the escape-wheel teeth. Secure to the plate with the foot screw and reduce the length by filing so that, with a tooth resting on the free end, the freedom of the teeth at the roller's edge is equal, as in Fig 592. Secure the brass gauge to the detent steel by the foot hole and scribe a mark on the steel across the filed end, as shown by the dashed line in Fig 328 at stage 1. Drill the hole for the locking pin on the scribed line and the centre will be correct for the foot-hole centre.

Fig 328 shows the sequence for shaping the detent. At stage 4 the rough detent can be fitted to the carriage or plate for direct observation of the various elevations. During stage 5 the detent is brought to final dimensions with the exception of the spring. Reduce the surfaces gradually so that they come together to maintain a proportional strength. In this way the hand will grow accustomed to the increasing delicacy of the work.

Drill the steady-pin holes in the detent foot. With the escape wheel and roller in position check the freedom of the teeth with the detent fixed by its screw and a dummy locking pin fitted. Drill the steady-pin holes in the plate through the detent foot holes. Separate from the rod and finish the foot to shape. Finally reduce the thickness for the spring to 0.04 mm with a fine, sharp file. Grind the safe edges of the file square to the cutting face and with an oilstone remove the sharp teeth from the corners. It is important to avoid the danger of the corner of the file cutting into the corners of the detent spring to cause a fracture.

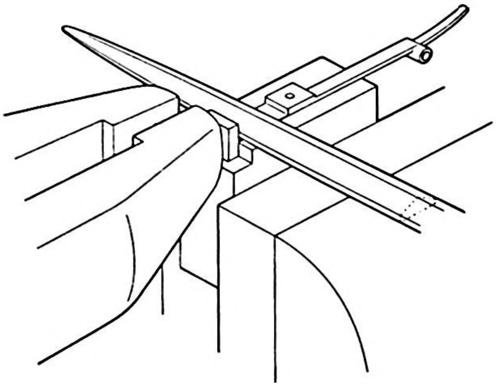
Hold the foot in a hand vice and rest the spring on a cork block cut to shape, as in Fig 329. The hand vice will prevent the spring going out of square during initial reduction. When the spring is reduced



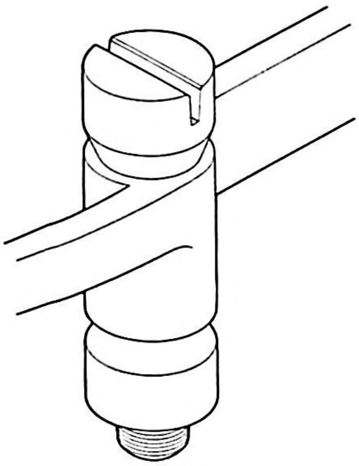
328 Six stages in making a spring detent:

1 Drill foot and locking-pin holes
2 Reduce to width of locking-pin pipe
3 Reduce height to fit under escape wheel
4 Reduce foot and form lower banking pipe
5 Reduce overall to required dimensions and shape locking-pin pipe
6 Separate from the rod and finish foot and spring

to about 0.06 mm the holder will no longer be necessary and the spring can be flattened and reduced to 0.04 mm while held to the cork by a smear of beeswax. In this final stage of filing only a very light pressure must be applied to the file to avoid unsticking the spring or causing it to bow by distorting the cork. Although the



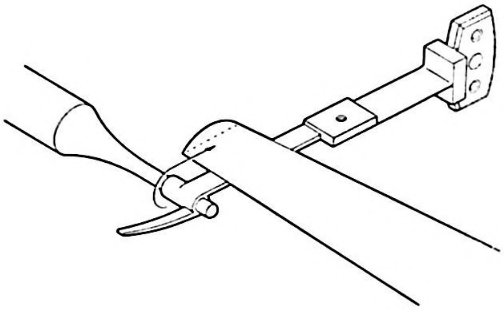
329 Reducing the spring thickness while supported on a cork block



330 Hard steel plug for shaping the pipe

cutting is of the very lightest it is important to use a sharp file. A dull file will burnish the surface and cause irreparable distortion. Use the hard steel plug, shown in Fig 330, to help guide the file while reducing the wall thickness of the locking pipe. It is in the form of a steel screw and nut tapered at the flange to centre in the drilling.

Finally fit the detent complete into the frame and adjust the horn to bring the passing spring to the balance-staff centre. After hardening and tempering finish all flat surfaces while resting on cork. Use oilstone paste and iron polishers for the initial cleaning and smoothing. Fit the locking-stone pipe to a rod and clean with a sharp-cornered stone. Smooth with oilstone paste on wood, as in Fig 331. Fit the foot to a similar rod to clean the edges and bevels, or fix with a screw to a flat rod, as in Fig 332.

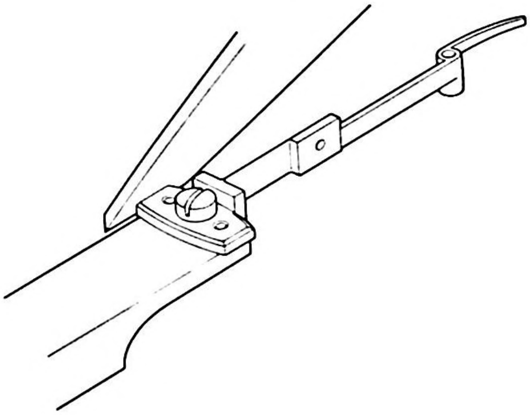


331 Cleaning the surfaces

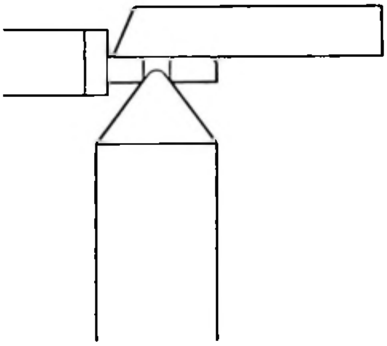
Chamfer and polish the steady-pin holes. Finish the foot flat on a pointed brass post, as in Fig 333. This will allow the foot to find a level beneath the polisher. If a polished finish is required the whole process must be repeated with diamantine paste and hard brass polishers. But a straight-grained detent with bevelled corners is much the smarter. Finally fit the steady pins, the locking stone and the passing spring.

Pivoted Detent

The form of the detent is a matter of individual preference. The dimensions are taken from a drawing of the escapement.



332 Finishing the foot

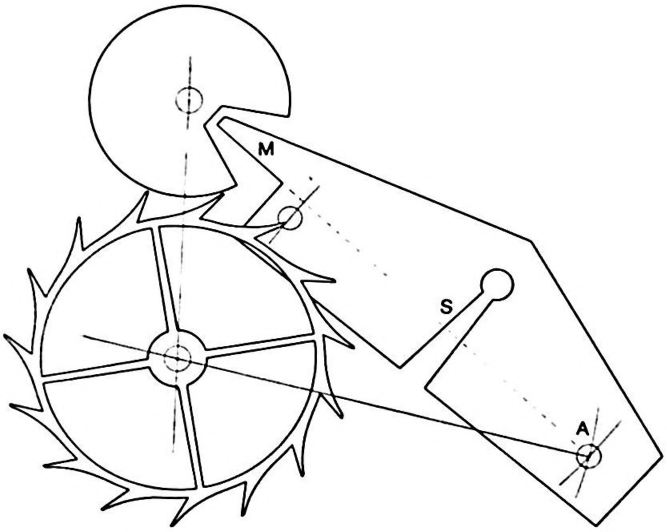


333 Polishing the foot

With a compass set to the vernier gauge (Fig **224**) scribe arcs on the watch plate for the position of the detent pivots from the balance and escape-wheel centres. At the intersection of the arcs drill a hole of 0.5 mm diameter. This will be opened later to take a jewel hole.

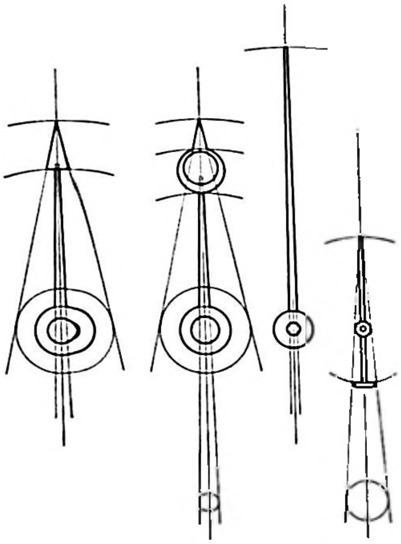
Lock the escape wheel with a cut-away dummy roller pivoted in the balance centres. Drill a 0.5 mm diameter hole in a thin plate and pin this beneath the escape wheel at the detent pivot hole *A* in Fig **334**. Mark the plate beneath the locking tooth with the position of the locking-pin hole. Drill the hole and fit a brass locking pin. Check that the freedom for the teeth at the edge of the roller is equal. If there is any error make a saw cut *S* across the plate and open or close the slot as necessary to obtain exactly equal clearance of the teeth at the roller.

With the locking pin set to the required depth of engagement with the locked tooth make a mark *M* on the edge of the plate for the



334 Drilling template for a pivoted detent

position of the balance centre. The horn of the detent will lie on a line between this mark and the pivot position. The plate can now be used as a template to drill the final detent correctly and locate the horn.



335 Marking out symmetrical hands

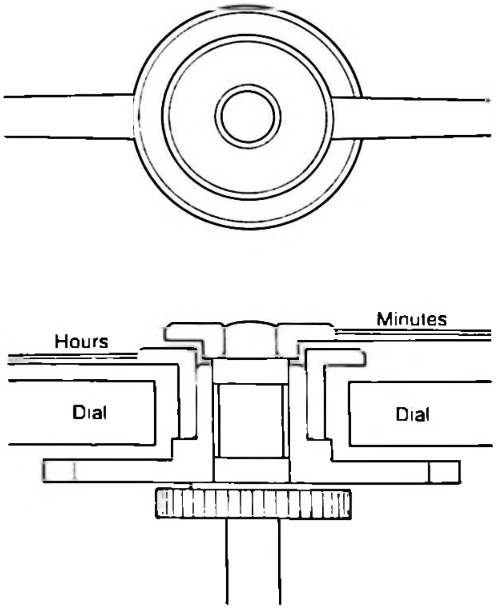
Hands

While the style of the hands of a watch is essentially a matter of preference, they should naturally always draw the eye to the indicated information. Fussy hands divert attention and can lead to loss of purpose in the general appearance of the dial. The hands should complement the dial and produce an harmonious whole. The hands of the watches illustrated are of simple form.

Gold or blued steel are the most usual materials. With only slight variations, the methods for fashioning are the same for both materials. Drill the hole for the boss of the hand on a scribed centre line. Mark off the total length and finally scribe the outline. Fig 335 shows the method for ensuring symmetry with the scriber.

Running Clearance

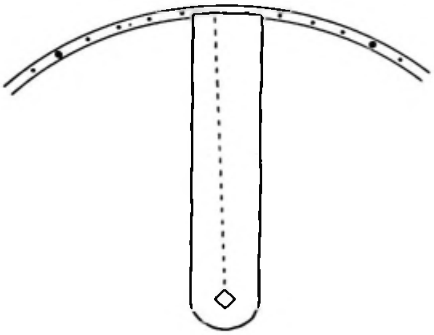
Note that in Fig 336 the boss of the minute hand is large enough to cover the hole in the hour hand. The end clearance of the hour wheel is taken on the underside of the minute-hand pipe. The pipe of the hour hand extends down to the flange of the hour wheel. When fitted in this way the clearance between the hands remains constant after removal and replacement.



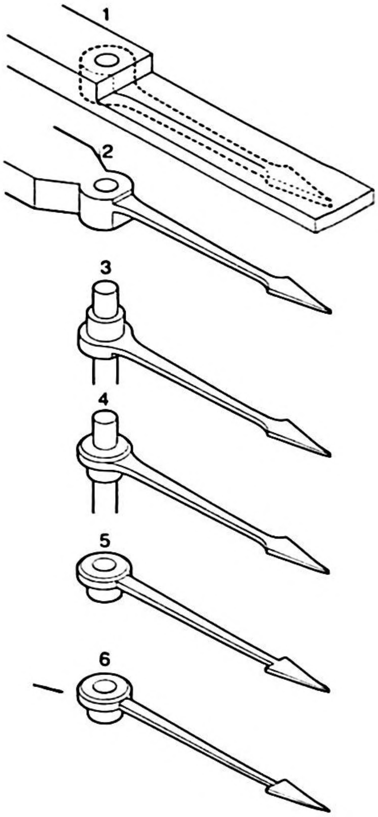
336 Running clearances for hour and minute hand centres

Repeating Watch Hand

When the minute hand requires a square hole, as for a repeating watch, this must be completed before the centre line is scribed. Fit the material to the cannon pinion and lead it slowly to the sixty-minute mark on the dial. The mark is reached when the quarter snail flirts. Scribe the centre line to coincide with the mark, as in Fig 337.



337 Aligning a square hole for a minute hand

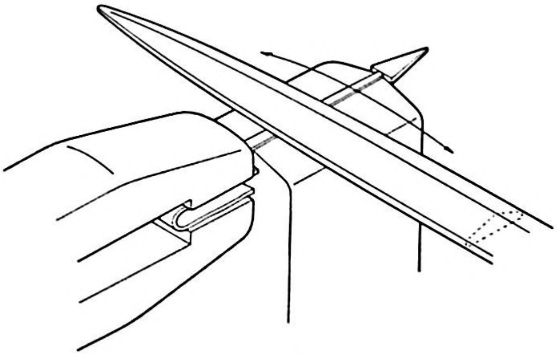


338 Six stages in making a hand:
1 Drill centre hole and file lower surface step
2 File upper surface step
3 Turn fitting pipe
4 Turn upper bevel
5 Shape shank and spade
6 Curve upper surface of shank

Shaping the Hand

Complete the outline of the hand and cut away the surplus material with a piercing saw. As shown in Fig 338 reduce the hand to the required thickness by filing on both sides up to the circle for the centre boss. Fit to an arbor and turn both sides of the boss to finished dimensions leaving a bevel to define the upper edge. Complete the shape up to the scribed outline and finally curve the upper surface of the needle.

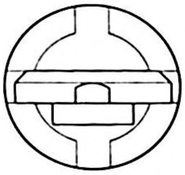
In the early stages of shaping, the hand can be held in the hand vice. As it becomes more delicate, and especially while filing the upper curved surface and finishing the edges, rest the shanks in a grooved, wood support, as in Fig 339. Note the method of holding the hand by the boss in the paper-lined jaws of a pin vice.



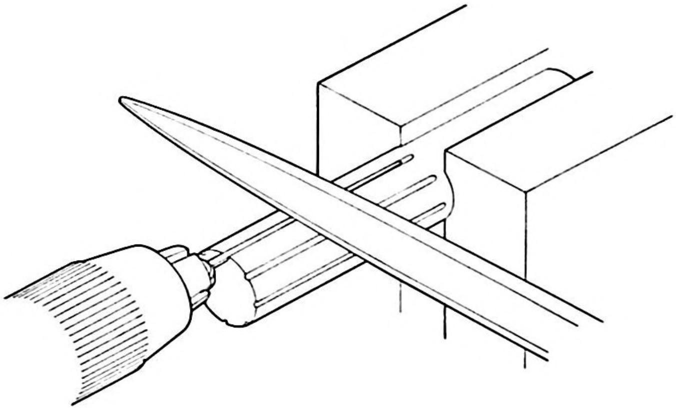
339 Curving the upper surface of the shank

Seconds Hands

Seconds hands, and other long, fine hands, can be filed in the same way but a grooved metal support will provide a more certain



340a End view of hand gripped in pin vice



340 Shaping long, thin hands

location for a thin hand. This can be made from a brass rod indexed in the lathe and grooved with a 'V' cutter. Hold the hand in a pin vice, as shown in Fig **340a**, while resting in the appropriately sized groove, as in Fig 340.

When a long pipe is necessary the hand can be made from thinner material and the pipe added. Long pipes are sometimes made of brass but steel is better. When a hand with a brass pipe is fitted tightly to its arbor the pipe may pull out when the hand is removed. Steel pipes can be more securely riveted to the boss of the hand.

Turn a carbon-steel rod to a tight fit in the hole in the hand. Centre with the graver and drill to the smallest diameter of the arbor. Clear away the metal behind the seat and part from the rod. Reverse in the lathe and centre the hole with the tailstock point. Turn the pipe to length and diameter. Open the hole with a broach to fit the arbor to the correct height. Check this by observing the height of the seat with the arbor in the watch. The sequence of operations is shown in Fig **341**.

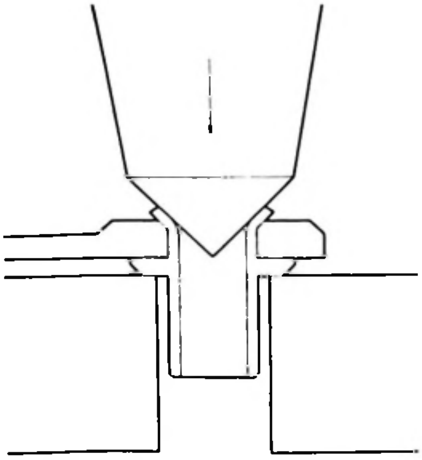
Harden in oil and temper to grey. Fit the hand and tap firmly down to the seat. Secure the hand with a punch in the staking tool. Use a pointed punch and open the mouth of the hole only to the depth of the surface of the hand boss, as shown in Fig 342. This will expand the metal to fill the tapered hole in the hand. Clean off the surface flush with the surface of the boss.

Gold Hour Hands

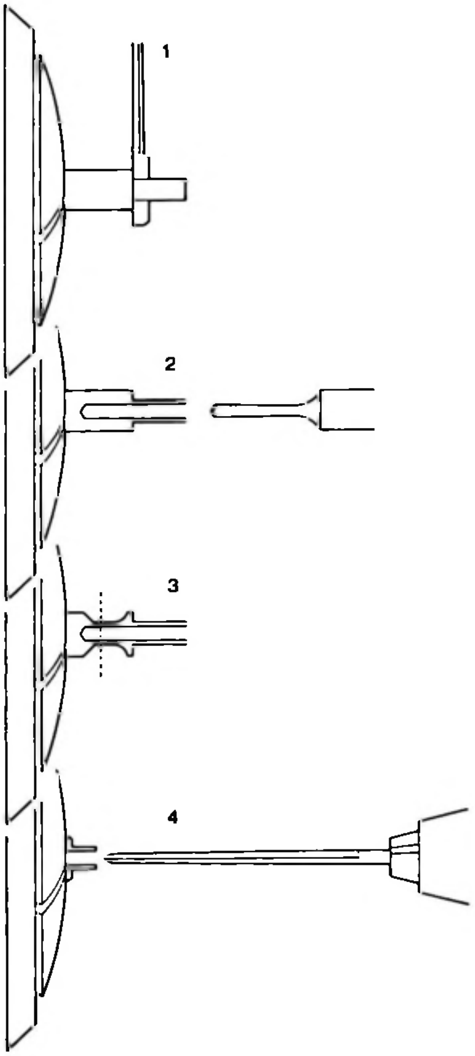
When the hands are made of gold the pipe of the hour hand is better made of steel. The method is the same as for the seconds pipe but the hole must be bored in the lathe to fit the hour wheel. With a thin file cut a slot through the diameter to make a sliding fit on the hour-wheel pipe, as shown in Fig **343**. Harden and temper to grey and fit to the hand, as in Fig **342**.

Steel Hands

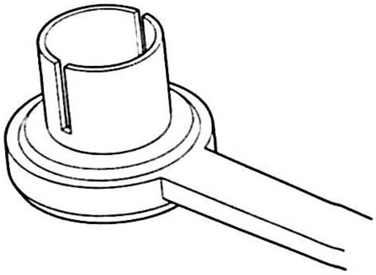
Steel hands should be smooth finished and hardened in oil. Temper to dark blue before final polishing and 'blueing'.



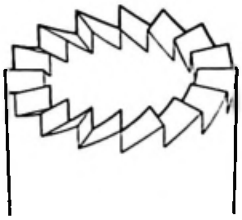
342 Securing the pipe



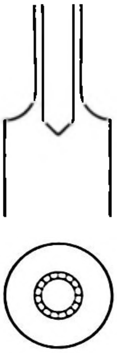
341 Four stages in making a hand pipe:
1 Fit hand to rod
2 Drill through to smallest diameter of tapered arbor
3 Reduce diameter of pipe and part off
4 Reverse in collet and open hole to fit taper of arbor



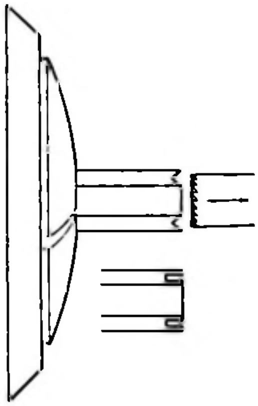
343 Flexible pipe to grip hour wheel



344a Machined teeth of cutter



344 Cutter for cylinder groove

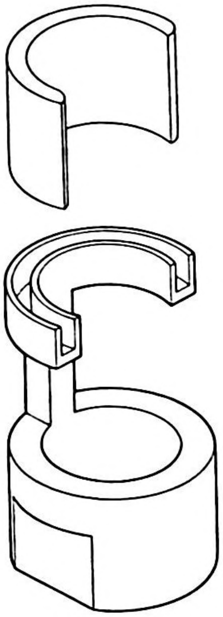


345 Cutting the Breguet cylinder groove

Ruby Cylinder Frame

Turn and drill a cutter to the form shown in Fig **344** and cut ratchet-shaped teeth as illustrated at *A*. Use the dividing head to ensure that the teeth are of uniform height. If cut by hand they will not be uniform and the cutter will not cut true. The completed cutter must be of the exact dimensions as the cylinder to be fitted.

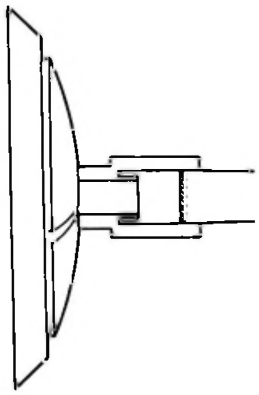
Drill and turn a piece of steel rod in the lathe to the form shown in Fig **345**. The diameter of the bore will be the diameter of the hub to which the carrier will be fitted. The depth should be one and a half times the required length of the finished carrier. Make a groove at the mouth as illustrated to help start the cutter true.



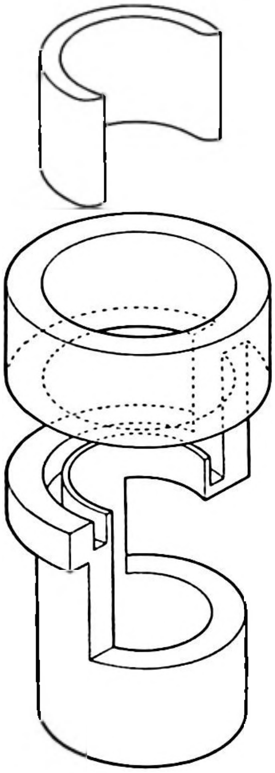
346 Breguet cylinder frame

Cut the groove for the cylinder to a depth equal to a quarter of the diameter of the cylinder. Keep the cutter well oiled and withdraw frequently to clear the swarf. Try the cylinder in the groove. It must be an exact fit. If the cylinder is slack reduce the cutter with an oilstone slip and start the cut again. If the cylinder will not enter the groove easily, rub a burnisher over the tips of the cutter teeth to form a burr at the edge and re-cut the groove. There will be very little metal to remove and the burrs will manage quite well. When satisfied with the fit, file away the surplus tube to the form shown in Fig **346**. Harden in oil and temper to a medium blue. The carrier is now ready for polishing.

The English ruby cylinder frame is made by the same methods but the rod is turned, as shown in Fig **347**, and the surplus filed away to produce the shape illustrated in Fig **348**. The upper ring will fit the balance hub and the lower will receive a brass plug to take the pivot.



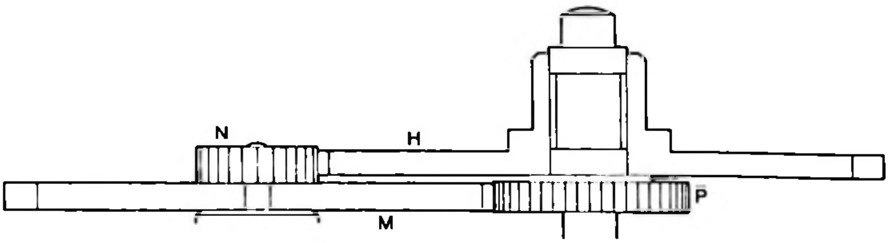
347 Cutting the English cylinder groove



348 English cylinder frame

Motion Work

The conventional form of motion work for watches is shown in Fig **349a**. The pinion *P* carries the minute hand and drives wheel *M* carrying the pinion *N* to drive the hour wheel *H*. During hand-setting the pinion *P* may revolve on the centre-wheel arbor. This is the method used for keyless watches in which the pinion is a light friction fit on the arbor.

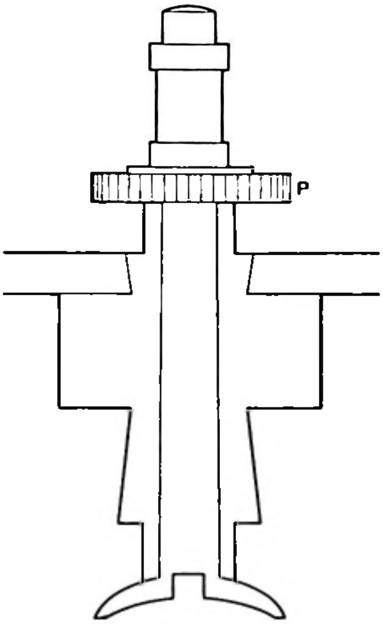


349a Elevation of conventional motion work

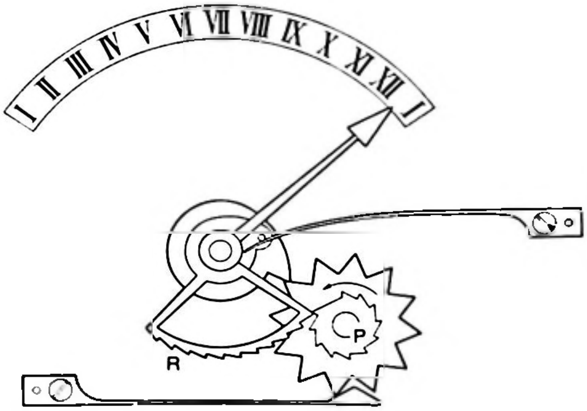
In Fig **349b** the arbor carrying the pinion *P* can revolve in the hollow centre pinion. The fit in the pinion is tapered to provide the friction fit. Turn each end of the taper to fit the hollow centre pinion using the methods shown in Figs **114** and **115**.

It is not necessary for watches to have concentric hands. They may be placed anywhere on the dial within subsidiary circles for their indications. In such cases the motion work can be arranged to link the separate hands together for hand setting or they can be separately set.

The watch shown in Plate III has concentric hands but the hour hand is retrograde so that normal motion work is not suitable. The watch employs a star wheel, as in Fig **349c**, which is turned one tooth every hour by a finger on the centre arbor. The rack *R* is advanced by the pinion *P*. This has one short tooth to allow the rack to fall back at 1 o'clock.



349b Hollow centre pinion for setting arbor



349c Motion work for retrograde hour hand

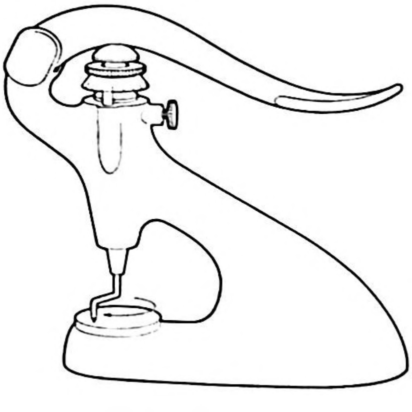
7

JEWELLING

The first use of jewelled friction surfaces for watches is attributed to Nicholas Facio and Peter Debaufre who jointly took out a patent for pierced jewels in 1704. The eighteenth-century English watchmakers developed the art and proved the value of hard stones for resisting wear and reducing friction. Good, modern watches have a minimum of fifteen jewelled surfaces but some have many more. The stones were originally cut from sapphire or ruby with simple tools held in the hand. Modern watches employ machine-made artificial stones manufactured to uniform appearance and close tolerance.

Standard-Sized Jewels

The colour and shape of modern jewel holes make them unsuitable for old watches in which they would look out of place. When constructing a new watch the colour of the stones should be matched throughout and nowadays this is most easily done by using artificial stones. These can be purchased from material suppliers in a range of sizes of outside diameter and hole size to suit almost all of the watchmaker's requirements. Cap jewels and locking and impulse stones are also readily available in graduated sizes. The methods of manufacturing the stones ensure uniformity of size and surface finish. The holes of pivot jewels are concentric with the edge and polished to within 0.005 mm diameter for small holes and within 0.01 for larger holes of a size suitable for centre pivots. The exact sizing of the outer diameters is important, for the jewels are held in the watch plate by friction. The hole to receive the jewel is opened with a special broach 0.01 mm smaller than the diameter of the jewel, which is forced into the hole by a press tool. Pallet stones and impulse pins are fitted closely into the slot or hole as appropriate and secured with shellac.

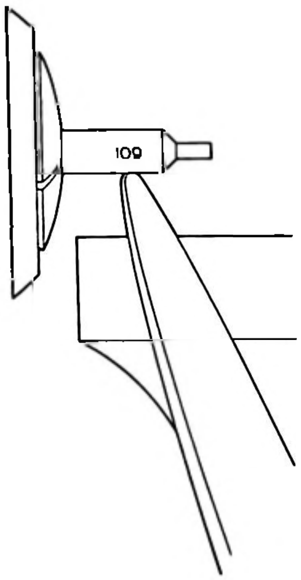


350 Jewel press tool

The tools for fitting the jewels are simple and consist of a press, as shown in Fig 350, with micrometer thimble to control the depth of the jewel below the surface of the plate, with a range of sized broaches for opening the plate holes, a range of sized pushers for pressing in the jewels and a selection of stakes for supporting the plate while pressing.

Checking the Press and Broaches

Before using the tool and accessories all should be checked for accuracy. Fit a pointer to the broach holder, as shown in Fig **350** and check for uprightness by slowly revolving the pointer. Any variation in the distance between the pointer and the base table indicates that the tool is faulty. Check the diameters of the broaches with a micrometer. The reading should be exactly the same as the number on the broach. If the broach is oversized it can be reduced with an oilstone slip or an iron polisher and oilstone powder applied to the parallel shank above the tapered cutting edge. Undersized broaches should be rejected.

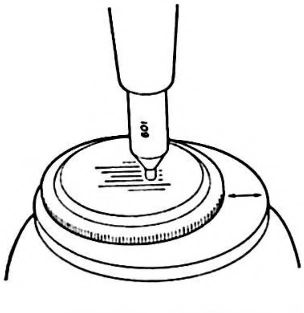


351 Checking for concentricity

Checking and Correcting the Pushers

Check the truth of the faces of the pushers by rotating them in the lathe. Fit them into the mouth of the collet and with the lathe slowly rotating bring the shank true with the end of the tweezers, as in Fig **351**. Now observe the pusher as it rotates and check that the reduced diameter is true with the shank and that the face is truly flat. Hold the point of the tweezers or some other convenient tool close to the face and observe the reflection. It should be quite stationary. If there is any wobble then the pusher is not suitable for use without correction. If the reduced diameter is eccentric there is a risk of damaging one side of the plate hole when working to close limits and the pusher should be rejected. Concentric pushers with out-of-flat faces can be corrected with the flat stone supplied with the tool, as in Fig **352**.

Where a pusher is fitted with a sprung centring point check that both hole and point are concentric. If the hole is eccentric the pusher should be rejected. If only the point is eccentric it can be removed and made true.



352 Correcting the face of the pusher

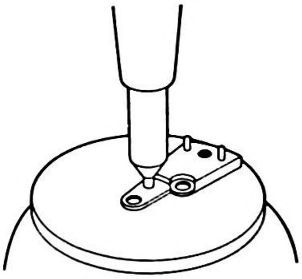
Checking and Correcting Stakes

The stakes must be checked for parallelism of the face and resting shoulder. Put the stake in the lathe and make true as before. Check both faces with a pointer. If one or both faces wobble then the stake must be corrected before use. The stakes are hard and will need to be softened to make a correction. Raise to red heat and allow to cool slowly. Return to the lathe and take a fine cut with the slide rest across the face and up to the shoulder. To re-harden, raise the stake to red heat and drop, upright, into oil. Unless the stakes are to be subjected to continuous use they do not, in fact, need to be hard. The face can be smoothed with a fine buff stick after truing. This will inevitably remove the sharp corner of the edge but it will be an improvement for it cannot scratch the watch plate.

When purchased new, the jewel-fitting outfit has a convincing air of precision reflected in the shining, freshly ground rows of pushers and stakes. The purchaser could be excused for believing that such an outfit represented the solution to all his jewelling difficulties. It should be remembered, however, that the slightest error in uprightness or flatness will make the fitting of the jewel defective and cause difficulties in the finished work that are sometimes difficult to trace. It is only by the most diligent attention to the truth of the tool that it can prove its ultimate worth.

Pressing in the Jewels

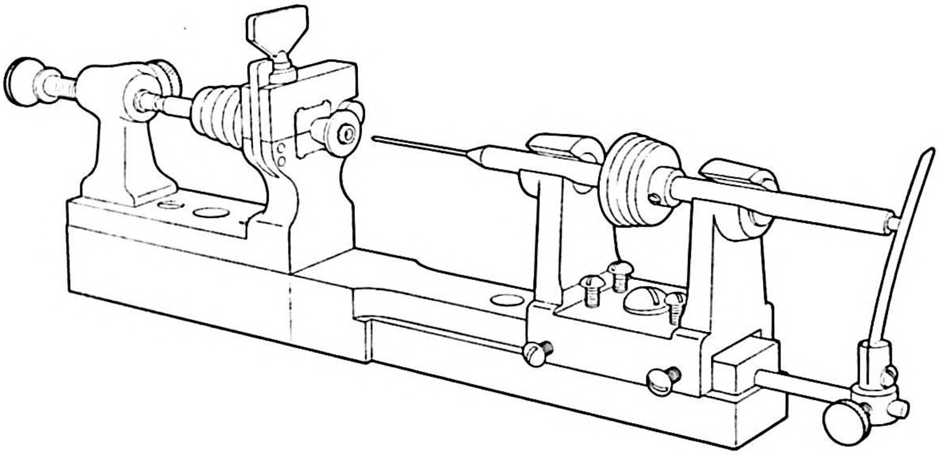
Drilling and opening the holes to size ready to receive the jewels is described as appropriate to the work in hand. Before fitting the jewel hole, slightly chamfer both sides of the plate to remove the sharp edges. Select a suitable pusher of a size smaller than the full diameter of the jewel. Bring the pusher down on to the surface of the plate, as in Fig **353**, and set the thimble down not less than 0.05 mm. This will ensure that the jewel is safely beneath the surface and securely seated. Place the jewel on to the hole – it will not enter – and carefully press home until the pusher holder meets the thimble. If the tool has been carefully checked and the broaches properly sized, the jewel will be a perfect fit and precisely flat.



353 Setting the height of the pusher

Cutting and Shaping Stones

The range of sizes of the standard jewels available has been developed to suit the requirements of the modern watch industry. For the maker of individual watches this range is not always adequate, and he must learn to cut jewels to suit his own requirements. This is also true of the watch restorer who may need to cut stones to match the colour and shape of damaged jewels.



19th-century jeweller's lathe

Cutting Paste

The stones are cut and polished with diamond powder applied with circular mills used in a lathe. Suitable grades for 'roughing', 'smoothing' and 'glossing' are available from firms specializing in the preparation of the powders in paste form for industrial purposes. They are graded according to the size of the grains of diamond and the density of grains in the paste. The watchmaker will need 'fine cutting' for roughly shaping the stones, 'smooth finishing' for smoothing or polishing the surfaces and 'super-fine polishing' for the final glossing. A medium paste density will be found suitable for each grade.

In the past lapidaries were obliged to prepare their own pastes and the following account was described to me by the late Professor David Torrens, whose pastime was the study of watchmakers' methods:

> A quarter carat of diamond is crushed in a mortar until reduced to powder. The powder is then examined for irregularly shaped pieces suitable for use as drills and these are put on one side for future use. A small vessel about one inch deep is filled with olive oil, and the powder poured in and stirred to ensure even distribution. After half an hour the liquid is carefully poured into a second container leaving the 'dregs' in the first. These are again examined for useful sharp pieces which are removed and the remainder given a further crushing with a hammer or hard steel roller. This powder is then used for the roughing mill and, with further crushing, for the smoothing mill.
>
> After two hours the liquid is again poured off and the 'settlings' used for fine cutting such as oil sinks and enlarging holes. The final decanting is left for 'at least several days' to produce the final polishing paste.

The decanting or 'settling' had to be done at a 'moderate' temperature to ensure uniformity of the viscosity of the oil. This would no doubt be to ensure uniformity of grain size when repeating the process.

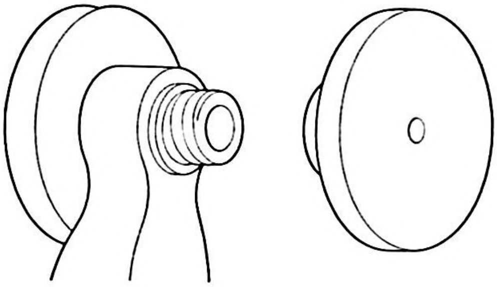
Preparing the Mills

The roughing and smoothing mills are made from copper discs of about 50 mm diameter and 3 mm thick. They should be easily detachable from the lathe spindle and run true when replaced.

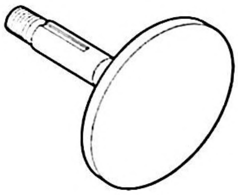
Turn the surface flat and finish the roughing mill with a No. 8 flat file. This will leave a surface finely grained to receive the diamond paste. Roll the paste into the surface with a hard steel roller. Wipe off the surplus paste which could roll between the face of the disc and the stone to be cut and cause chipping.

Finish the polishing mills with very fine emery paper and apply loose paste as required. Fine paste can be mixed with oil to make it stick to the face and this will act as a lubricant. Course mills need lubricating with water. Keep a small piece of wet sponge in contact with the face.

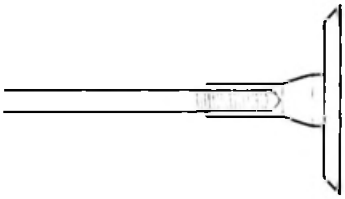
The ordinary turning lathe can be used for jewel making but the danger is always present that it could be damaged by diamond paste or the water used as a lubricant for the mills. It will require a headstock with revolving spindle, some means of supporting the work in progress and an adjustable lapping spindle to work in conjunction with the headstock.



354 Lathe with threaded nose-piece



355 Lap with collet shank



356 Alternative thread for laps

An old collet lathe is ideal and Fig 354 shows an example with the spindle adapted to take threaded mills. The mills can equally well be fitted to shanks turned to the form of a collet as in Fig 355 and, if no collet thread die is available, secured as in Fig 356. The only essential is that the mill must run quite true and be easily detachable. A table can be fitted into the 'T' rest holder so that it can be adjusted for height. The various pins and fittings for the table will be illustrated as they are required.

The watchmaker will need only small quantities of stone and these are best bought from an experienced stone dealer who can vouch for the type and quality of the stone. When stones are to be cut and shaped in quantities the blanks can be cut to size with a skive or slitting saw. This is a thin disc of hard copper or mild steel charged with medium cutting paste at the sides and edge. The cutting is done under a continuous flow of water to avoid heating that would chip or split the stone.

The stones are fixed to the lathe head with cement. The ordinary shellac used by watchmakers for cementing pallet stones is not suitable until its brittleness has been reduced by the addition of a softening agent. Sealing wax is tenacious if softened with a little resin or pork lard. When the cold wax can be marked by the fingernail it is in a suitable condition. Pitch serves well and is readily available.

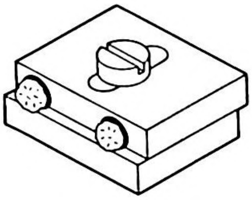
Selecting the Stone

The principal natural stone used in making jewels for watches is the sapphire. This varies in colour from blue, through colourless, to red when it is more commonly called ruby. The best watch jewellers were of the opinion that the ruby stone lacked the uniform hardness of the sapphire.

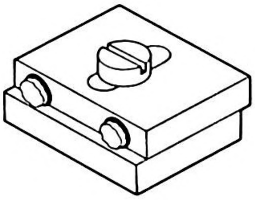
The watchmaker with no experience of stones is advised to seek the guidance of an experienced lapidary when selecting pieces for jewel holes, ruby cylinders and duplex resting stones. These pieces need piercing along the axis of crystallization to avoid difficulty in polishing and risk of splitting. The lapidary can supply the correct material rough-cut to size and with the axis running in the right direction. Artificial sapphire is now more readily available. It can be polished on any axis but requires greater care to avoid chipping. It is harder and more brittle than natural stone.

To Make a Jewel Hole

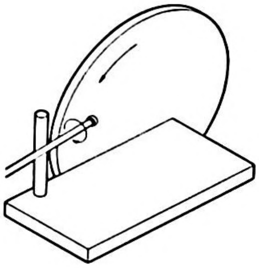
When making a jewel hole to replace a damaged one use the old hole as a pattern for the colour and shape. If this is not practicable take the style from existing good jewels and make the new one to suitable dimensions.



357 Tool to hold stones for rough-milling flat



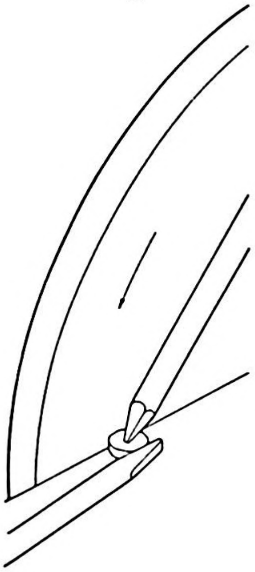
358 Second flattening



359 Roughing in the round

Roughing the Stone

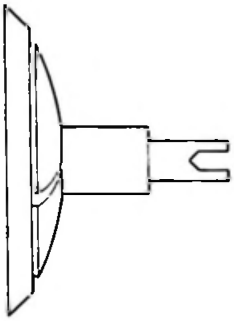
Shellac two pieces of stone to a plate, as shown in Fig 357, and flatten one side with the roughing mill. Two stones will ensure that the surface is cut flat. Remove the stones and reverse them so that the flats are against the block. Again, with the roughing mill, grind the surfaces flat, as in Fig 358. Remove from the block and cement one to the end of a brass rod. Rest the rod against the pin of the table and make the edges circular. The rod should be slightly larger in diameter than the finished jewel will be and the stone reduced until the rod begins to touch the face of the mill, as in Fig 359. Hold the stone lightly against the mill to prevent it detaching. With practice the rough rounding can be done by laying the stone on the table and manipulating it with two sticks, as in Fig 360.



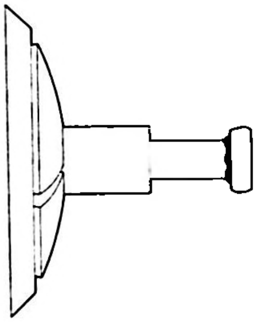
360 Roughing in the round

Making the Hole

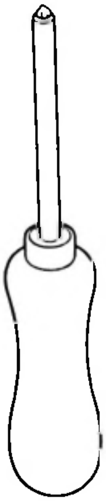
Put a brass rod in the lathe, turn the end true and make a small drilling to give freedom to the jewel piercing drill, as in Fig 361. Cement the stone to the face of the rod and centre by eye ensuring that the stone projects all round the edge of the rod, as in Fig 362.



361 Brass chuck for jewel

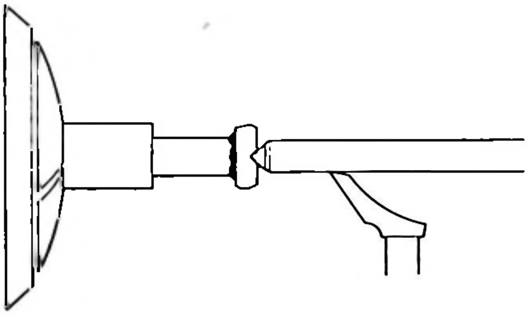


362 Jewel cemented to chuck

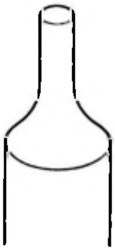


363 Diamond centring tool

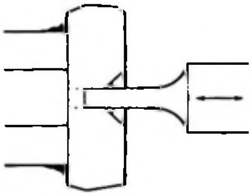
Make a small chamfer at the centre of the stone with the diamond tool shown in Fig 363. This is a sharp splinter of diamond set into a brass rod. Steady the tool on the 'T' rest and with a gentle pressure



364 Catching the centre



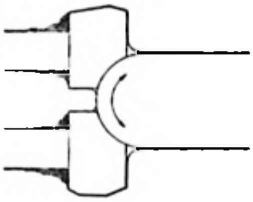
365 Steel piercing drill



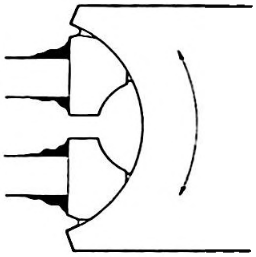
366 Piercing the hole

catch the centre of the stone with the point, as in Fig 364. The depth of the chamfer will depend upon the diameter the hole is to be. For small, shallow holes the chamfer can be deeper and this will ease the work of a small drill. Turn the drill from steel to the form shown in Fig 365. Harden and temper to a grey colour.

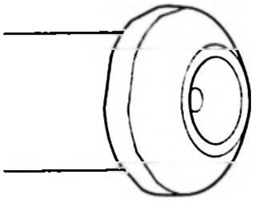
Apply medium diamond paste to the chamfer. Fit the drill into the tailstock and dab gently into the centre of the chamfer while the stone rotates at about 1,000 rpm. When the centre is established the pressure can be increased very slightly. Too much pressure will distort the drill and cause the drilling to wander. Dab the drill continuously into the hole, as in Fig 366, for two-second intervals, withdrawing it completely after each pressure. This will ensure a continuous supply of powder to the bottom of the drilling and prevent rapid wear of the drill. Observe the tip of the drill frequently and each time it begins to form a point flatten the end with an oilstone. After a few minutes the drill will pierce the stone and care should be taken to ease the pressure at the moment of piercing to avoid chipping the back of the stone.



367 Forming the oil sink



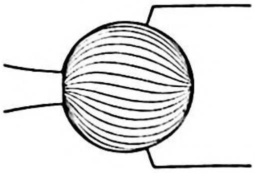
368 Forming the dome



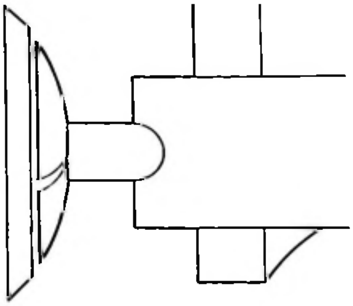
369 Flat separation of sink and dome

Forming the Oil Sink

With an annealed steel peg filed to a round end, as in Fig 367, form the oil sink with medium cutting powder and oil. Form the dome in the same way with a hollow steel peg, as in Fig 368. If the finished hole requires a flat at the meeting of the sink and dome, see Fig 369, judge the grinding to allow the necessary flat circle which will be polished last. When satisfied with the proportions finish the dome with brass or copper pegs formed with a circular rose cutter, as in Fig 370. If a suitable cutter is not available for the sinking peg, drill a



370 Shaping the polisher for the dome

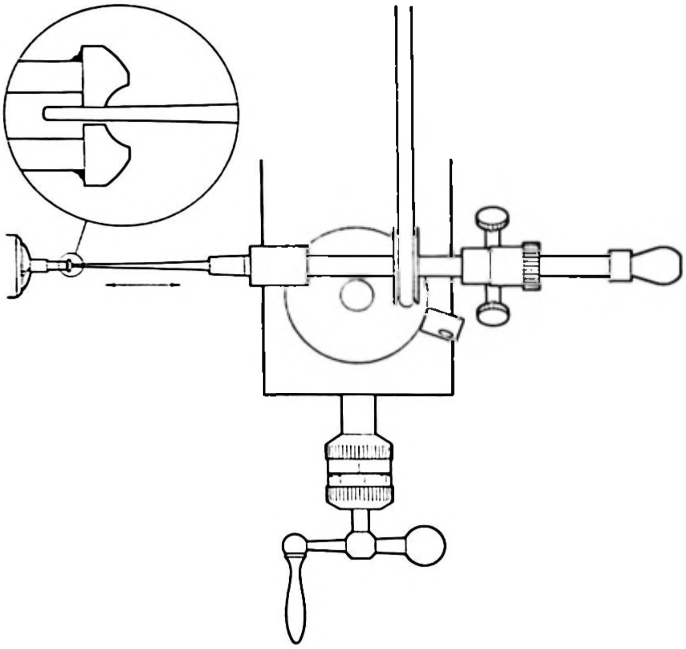


371 Shaping the polisher for the sink

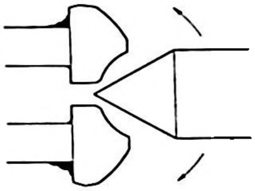
hole in a steel plate, and use a half diameter supported on the 'T' rest to form the end of the peg, as in Fig 371.

Polishing the Hole

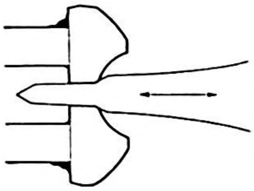
Polish the hole with a copper pin and fine finishing powder. Roll the powder into the pin with a burnisher. This will both secure the powder and stiffen the pin to resist bending. Pass the pin into the hole and work it in and out against the edge of the hole as the stone revolves at very high speed. Do not allow the pin to wedge in the hole for this would cause chipping. The polishing can be speeded up by contra-rotating the wire in the internal polishing spindle, as in Fig 372. Relieve the corners of the hole with a copper point and fine finishing powder, as in Fig 373. Finish the hole with a piece of tortoiseshell or a prong from a comb filed to a point and forced into the hole with fine finishing powder, as shown in Fig 374. True the edge of the stone with the smoothing mill on the polishing spindle, as shown in Fig 375.



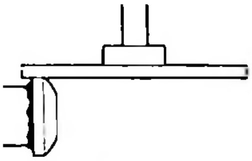
372 Contra-rotating boring spindle



373 Relieving the corners of the hole



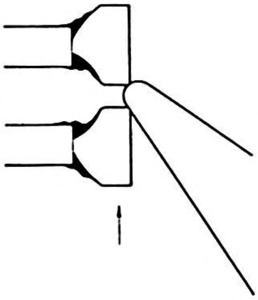
374 Fine polishing the hole



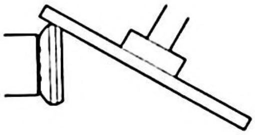
375 Truing the edge

Chamfering the Edge

Remove the stone and reverse it on the brass rod. Centre at the hole while still warm, as shown in Fig 376. Finish the corner of the hole with the copper point and chamfer the edge of the stone with the smoothing mill, as in Fig 377.



376 Centring the stone in reverse

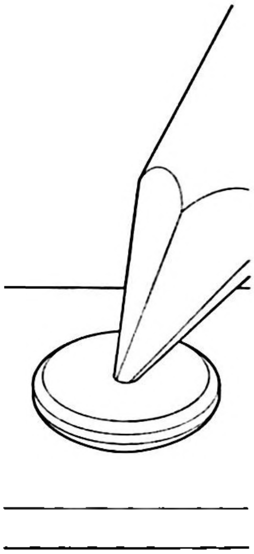


377 Bevelling the edge

Flattening the Surface

Remove the stone from the rod and flatten the underside and, if required, the upper surface of the dome. The latter is best done underhand on glass with fine polishing powder, as shown in

Fig 378. The underside would take too long to finish in this manner and is held on the smoothing mill by the pad of the finger covered with a piece of wet chamois leather. Keep the table close up to the mill to catch the stone should it slip out from under the leather. Finish with the fine polishing mill. It will be seen that this method introduces a slight curve to the face due to the stone moving under the finger. This curve is very slight and will have no effect on the finished quality of the jewel. If the surface is preferred dead flat, finish finally on the glass plate, as in Fig 378.

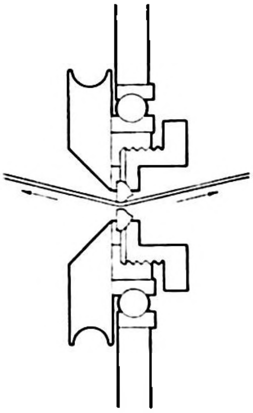


378 Polishing the flat

Polishing Small Holes

Very small holes are tedious to polish with tapered wires which are easily bent if too much pressure is applied.

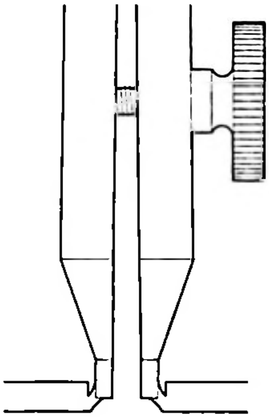
The device shown in Fig 379 will rapidly open a small hole as the paste-coated wire is passed to and fro through the spinning jewel. The spinner is a small, brass, clamping collet fitted into a ball bearing. Turn the pulley and body of the collet from one piece of brass rod. Fit the jewel between brass washers turned to fit individual jewels and clamp with the threaded end-piece. The fine copper wire used for small electrical coils is ideal for carrying the paste. Rotate the jewel at 2,000 rpm and make long steady strokes of some 300 mm with the wire pulled against one side of the hole. This process, in addition to enlarging the hole, will make its walls curved which is especially useful for balance-staff pivots. Such curved walls are described as olive holes.



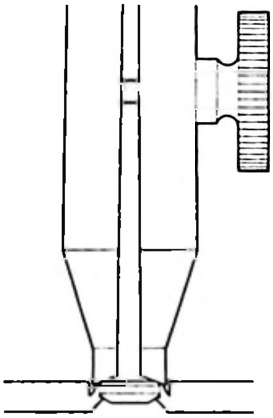
379 Method of opening small holes

To Fit the Jewel

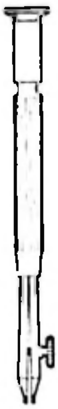
If the jewel is to be fitted into an existing rubbed setting it will, in the final milling of the diameter and chamfering, have been made to fit the setting. Raise the edge of the setting with the tool illustrated in Fig 380 and as used in Fig 381. Place the jewel into the setting and rub down the flange with the tool, shown in use in Fig 382. This will be done much more surely in the lathe with the plate centred on the mandrel. By this means the closing tool is not strictly necessary and the flange can be turned with a burnisher. Set the jewel into the



381 Method of opening settings

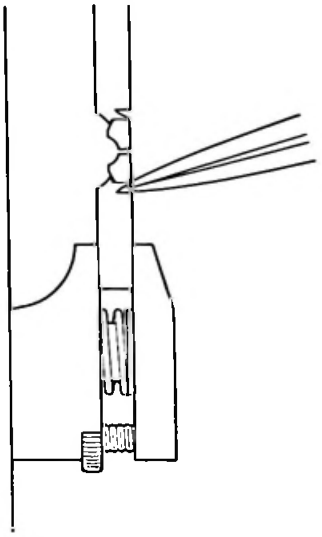


382 Method of closing settings

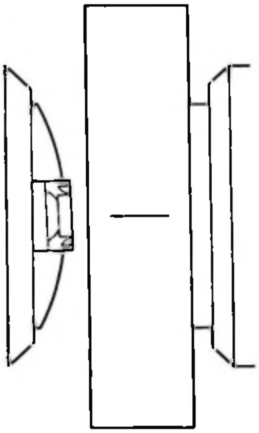


380 Tool for opening settings

setting with oil to retain it in position while the mandrel is rotating. Apply the closer or burnish the flange with the rounded points of the tweezers, as in Fig 383.



383 Closing the setting in the lathe



384 Truing the setting

If the jewel is set into a screwed setting, put the setting into a collet in the lathe and make true by bringing up the tailstock pad, as in Fig 384. Fit the jewel as described above.

Making a Setting

Turn a brass rod to fit the hole in the plate. The setting is usually slightly tapered to ensure a close fit in the plate. Drill a hole and bore true to the smallest through diameter, as in Fig 385, stage 1. Bore the mouth to take the jewel, as in stage 2. Turn the groove for the flange, as in stage 3. Part off the setting.

Turn a sink in a piece of brass to take the original setting or, for new work, to the required diameter and depth. Put the setting into the sink and file flush with the surface of the plate, as shown in stage 4. Place the setting in the lathe collet and make true, as in Fig 384. Turn and polish the slope, as in Fig 385, stage 5. Use a polished graver dabbed on the tongue to lubricate the cutting edge and produce a smooth surface to the slope. Finish with wood and diamantine.

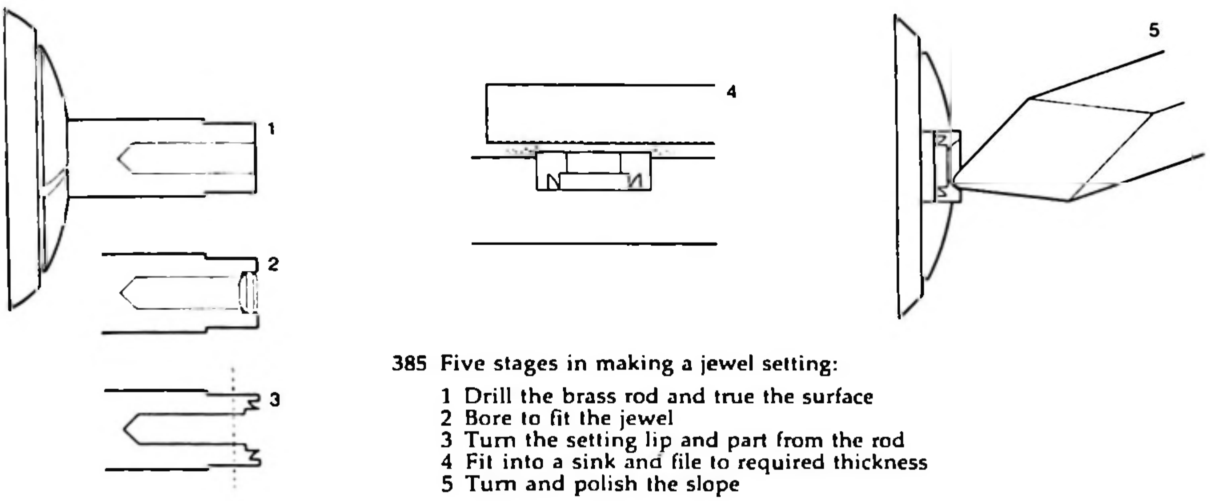
Press the setting firmly into the watch plate and complete the sinks for the screw heads. If the setting is a replacement use the sinking cutter very carefully for it will be cutting on one side only and inconsiderate use will break off the guide pin.

Put the setting in the lathe and bring flat, as in Fig 384, and rub in the jewel, as shown in Figs 382 or 383. Polish the top surface smooth with diamantine on a zinc block and finish with diamantine on a tin block.

The Ruby Cylinder

Roughing the Stone

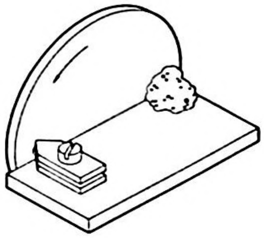
Make the stone flat on two opposite sides with the roughing mill, as described for Fig 357. Put the flattened stone in the clamp, as in



385 Five stages in making a jewel setting:

1 Drill the brass rod and true the surface
2 Bore to fit the jewel
3 Turn the setting lip and part from the rod
4 Fit into a sink and file to required thickness
5 Turn and polish the slope

Fig 386, and make it roughly cylindrical. Do this in equal stages by first making the stone square and then removing the corners, as in Fig 387. The final rough rounding is done by swivelling the clamp free-hand against the mill to relieve the corners. It is not necessary for the stone to be fully cylindrical but some care should be taken to bring it as nearly cylindrical as possible so that it can be set fairly true in the lathe for piercing.

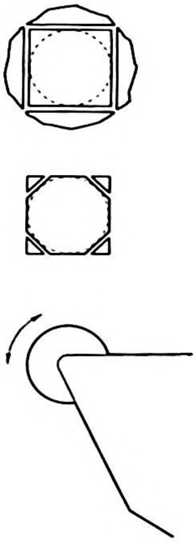


386 Rough-shaping the cylinder stone

Piercing

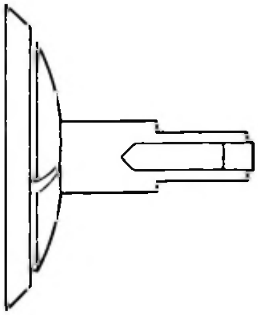
Put a brass rod in the lathe leaving about 30 mm protruding. Drill the end to take the stone, as shown in Fig 388. Note the reduced diameter of the rod and the depth of drilling. Cement the stone into the drilling. Turn the piercing tool from steel to the form shown in Fig 389. The largest outside diameter of the drill must be smaller than the final inside diameter of the cylinder by an amount equal to the thickness of the wall of the cylinder. This will ensure that, in the final polishing, the deepest scratches can be removed before the cylinder is to size.

With the corner of a square file, cut notches in the face of the tool, as in Fig 390. Harden the tool and lower the temper to a purple colour. Fit it into the tailstock runner and check for alignment with the stone. Exact alignment is important to prevent the tool piercing an oversized hole.

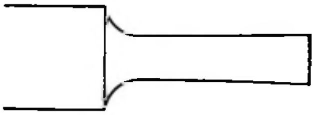


387 Method of reducing the stone

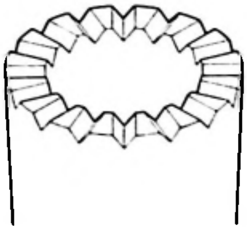
Put medium cutting paste on the face of the stone and run the headstock at about 500 rpm. Bring the cutter into contact with the stone and press gently. Hold the cutter in contact for short intervals (about three seconds) and withdraw completely to allow the paste to reach the cutting surface. When cutting correctly the work will be accompanied by a steady hiss. If the cutter rattles in the hole withdraw completely, wipe clean and recharge with fresh paste. Keep the paste loose with oil. If it is allowed to dry the cutter will wear rapidly. Fig 391 at *A* illustrates the position of the cutting paste at the correct consistency. Excessively high rpm will wear the cutter by centrifuging the oil away from the cutting face. A light pressure only is required to keep the cutter up to the cutting face. Excessive pressure will force the paste away from the tool and the cutting will stop. Be guided by the cutting hiss. If it diminishes apply fresh paste. A hole 1 mm deep can be completed in about ten to fifteen minutes. Proceed carefully towards the end of the cut to prevent the stone chipping as the tool passes through. The core will remain in the tool.



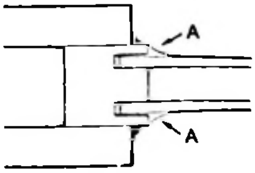
388 Brass chuck for mounting stone



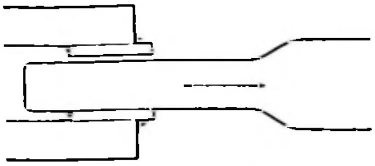
389 Steel core drill



390 Cutting face of core drill



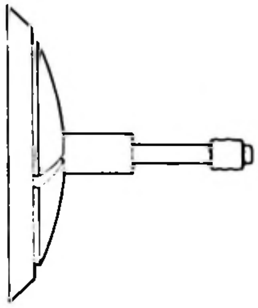
391 Cutting paste must remain in corners at A



392 Smoothing the bore

When the piercing is completed warm the rod and hook out the cylinder with a piece of wire. Do not remove the rod from the lathe. Carefully clean the cylinder in benzine and clean out the drilling in the rod with peg-wood. A drill can be passed lightly into the drilling to remove the bulk of the shellac and paste before applying peg-wood.

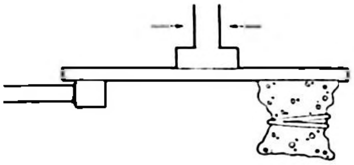
Re-cement the cylinder into the drilling and smooth the bore with smoothing paste on a copper peg fitted into the boring spindle, as in Fig 392. When all scratches are removed try the escape-wheel tooth in the bore. It should enter freely but without obvious clearance at the tips. If it will not enter continue with the smoothing peg until the desired size is reached. The freedom for the drop of the tooth can be adjusted during the final polishing.



393 Cylinder cemented to brass rod

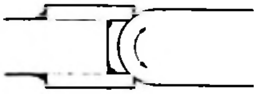
Reducing the Diameter

Apply heat to the rod and remove the cylinder. Turn down the rod until the cylinder will slide on freely, as shown in Fig 393. Warm the rod and coat with shellac. Slide the cylinder on to the warm shellac and allow to set.



394 Smoothing the outer surface

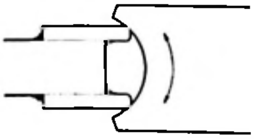
Make the outside diameter smooth, with the smoothing mill fitted to the boring spindle, as in Fig 394. For this operation revolve the headstock at about 200 rpm and the mill at about 500 rpm. Set the stop to control the spindle movement and prevent the mill following the irregular surface of the cylinder. When the cylinder is quite round, try the diameter with the escape wheel. It should pass between two teeth freely but without obvious freedom. If it will not pass the teeth, reset the spindle stop and further reduce the cylinder. It is important that the stop is used to control the depth of cut of the mill and prevent the cylinder becoming oval. When satisfied with the diameter, carefully clean the surface of the cylinder and polish with an ivory finishing mill charged with fine finishing paste. Rock the mill from side to side to prevent the cylinder deforming the surface of the ivory. The ivory mill will produce a brilliant surface to the cylinder very quickly. Try the escape wheel for size frequently during the polishing and stop when the drop is correct.



395 Chamfering the inner corners

Polishing the End Face

Finish the end of the cylinder with the fine copper mill used in the same manner as the ivory mill. Do not attempt to use the ivory mill for this operation. The cylinder may catch the soft surface and shatter. Chamfer the corners with copper pegs charged with fine finishing paste, as in Figs 395 and 396. Leave the other end unpolished to afford a key for the shellac when fitting to the frame. Remove the cylinder from the rod and boil off the shellac in methylated spirits.

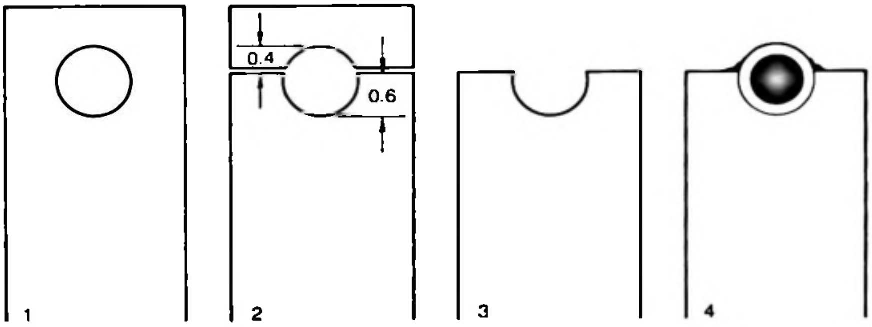


396 Chamfering the outer corners

Internal Finishing

Part off the end of the rod and again drill and bore with the slide rest so that the cylinder is a close fit in the hole. Warm the rod and dab the shellac on the mouth of the boring. Fit the cylinder while the rod is warm and observe that the face of the cylinder runs true.

Complete the internal polishing with a copper peg in the boring spindle, as in Fig 392, and finish with an ivory peg and fine finishing paste. Use the rocking stop to prevent the hole becoming oval and keep the peg moving axially in the hole. Polishing the inside of the cylinder is a slower process than polishing the outer surface but the diameter should be checked frequently with the escape-wheel tooth until the drop is correct.



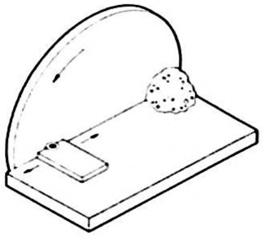
397 Template for cutting the cylinder

Cutting the Shell
The cylinder must now be reduced to form the final half shell.

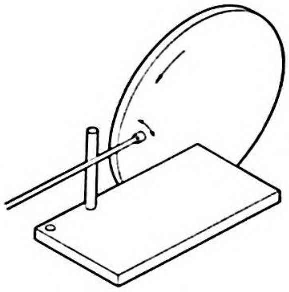
Drill a hole in a brass plate to take the cylinder, as in Fig 397, stage 1. Scribe a line to one side of the centre, stage 2, and file away the end up to the line, as in stage 3. Fit the cylinder into the hole and apply shellac to secure and, at the same time, fill the inside of the cylinder, as in stage 4. Lay the brass on the table, Fig 398, and remove the unwanted stone with the smoothing mill. The roughing mill would do the work faster but there is a danger of chipping the edge of the cylinder. Keep the surface of the mill wet and continually wiped clean with the water sponge. Any loose grit on the surface will certainly chip the cylinder. Keep the plate continuously in motion across the mill and apply only enough pressure to keep the stone in cutting contact. When the edge of the brass plate reaches the mill the work is complete and it only remains to polish the lips of the cylinder.

Polishing the Lips
The entry lip is simply formed by cementing the cylinder to a half-round rod and polishing the lip as shown in Figs 399 and 399a.

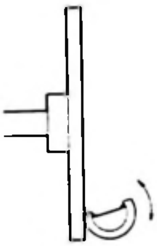
The exit lip must be polished internally and Fig 400 shows a simple and effective way to do this. Cement the cylinder into a hollow in the end of a brass plate and pivot this loosely on a pin fitted into a flat, table post. Adjust the post so that when the plate is towards the copper wire polisher the inner edge of the lip can be reached without touching the inner surface of the cylinder. At the other limit the lip must remain above the centre line of the wire. Fig 400a illustrates the limits of the movement. Hold the plate flat against the post and oscillate between the two limits to polish the curve of the lip. In the early stages the movement of the plate should confine the polishing to the highest point of the lip at the centre.



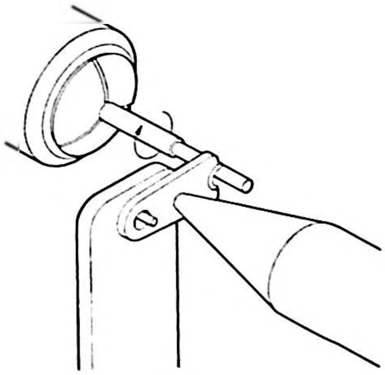
398 Cutting the shell with the smoothing mill



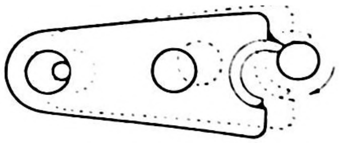
399 Polishing the entry lip



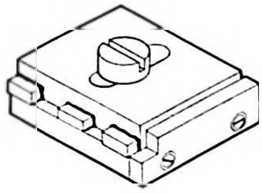
399a Detail of polishing the lip



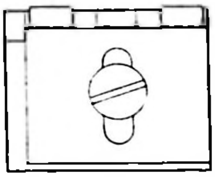
400 Polishing the exit lip



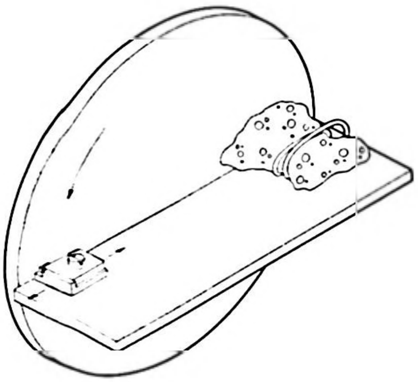
400a Detail of polishing the exit lip



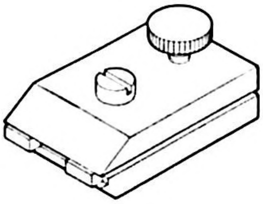
401 Tool for holding pallet stones



402 Adjustable table set to dimensions of pattern



403 Reducing the stones



404 Tool for small adjustments

To Shape Pallet and Locking Stones

Shaping flat-sided stones is simply a matter of finding the most convenient means of holding the stones while presenting them to the mill. Much material will be saved by using a slitting saw to prepare the blanks.

The stones can be cut to fit an existing slot or made to the required dimensions and a slot cut to suit. It is simpler to make a stone to fit a slot, for the cutter will usually cut wide and the stone will be slack if not made to fit. The difference between a close fit and a slack fit will be less than one hundredth of a millimetre but this is sufficient to leave the stone insecure even though it is held with shellac. Therefore shape the stone to fit the slot or make trial slots to find a suitable cutter.

The Pattern

It will be useful to make a pattern as a guide to cutting the stone. This can be put in the lapping tool and used to observe the progress of the work. Make the pattern in brass to the required final dimensions by filing. The impulse angle for a lever stone need not be filed exactly, but the total length to the tip of the impulse incline must be adequate.

Reducing the Stones

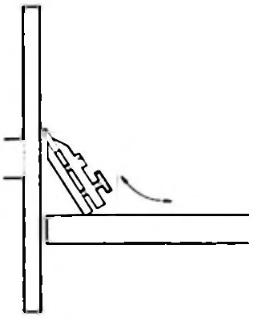
Cement the pattern and two roughly shaped stones to an adjustable block, as in Fig **401**. This block has a sliding top plate to adjust the depth of the stone to be cut and a rail along one edge to ensure that the leading edge of the sliding plate is kept square to the lower resting ledge. Set the plate so that the pattern is flush with the edge of the resting ledge, as in Fig **402**, while the stones project beyond. Rest the block on the table and, using the smoothing mill, slide the block across the face of the mill with a firm, gentle pressure, as in Fig **403**. The stone near the centre of the mill will cut more slowly than the stone near the edge. This is simply adjusted by reducing the pressure on the outer stone. Make sure that the stones are reducing at the same rate. When the pattern is close to the mill, change the mill for the fine polishing mill and complete the work by reducing the stones until the pattern almost touches the mill face.

Polishing the Surfaces

Turn the stones and smooth the backs with the smoothing mill. The pattern will now be very close to the face of the mill. Finish on the fine polishing mill until the pattern touches the face. The stones will now be completed on one dimension.

Repeat the process to finish the second dimension. Try the stones in their slots, after removing all the shellac from the surfaces. If further reduction is required, fit them to the tool shown in Fig **404**. This tool is more convenient for making small adjustments because the stones are clamped into position by the upper plate and shellac is not required. Note that the lower plate has a ledge at the front edge to ensure that the stones are square. Although only one stone may need reducing, both are fitted to the tool to ensure the squareness of the stone to be reduced. Fit the stone requiring greatest reduction towards the edge of the mill where the cutting is faster. If the inner stone does not need reducing do not apply any pressure but simply trail it near the centre of the mill while pressure is applied to the outer stone.

Use a similar tool, but without the ledge in the lower plate, for shaping the tips of chronometer impulse stones. Fig 405 illustrates the method of using the tool first on the smoothing mill and finally on the fine finishing mill.

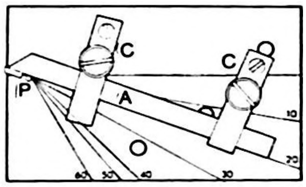


405 Shaping the end of the stone

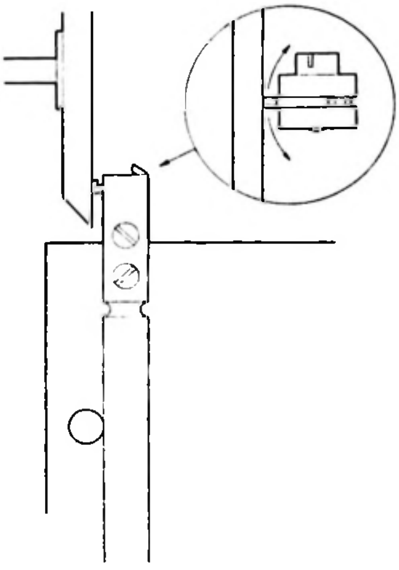
Lever Pallet Stones

The impulse angles of pallet stones are set to the required angle on the plate, as shown in Fig 406. The index arm *A* can be set to the required angle and held with the clamps *C*. The arm is located by the pin *P* to which the scribed angles are tangents. The stone is cemented to the arm and base between the pin and the edge of the plate. Reduce the stone until the edge of the plate touches the lap.

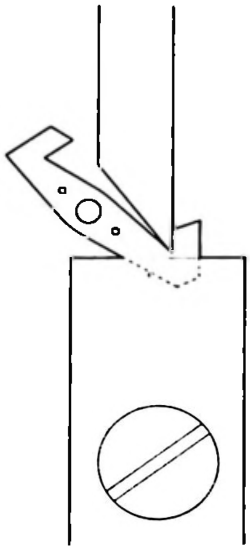
The curved, steel faces of the covered pallets are filed up to the scribe lines and checked in the depth tool, Fig 322. Cut the slots, as shown in Fig 323, and set the unpolished stones with shellac. Polish the edges of the stones with the pallets held in a long holder rested against the table pin, as in Fig 407. Note the sharp edge of the lap to reach into the corner of the exit locking face, shown in Fig 408.



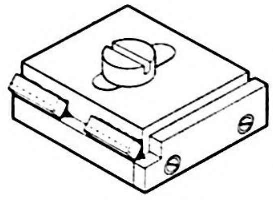
406 Tool for setting impulse angles



407 Polishing English pallet stones



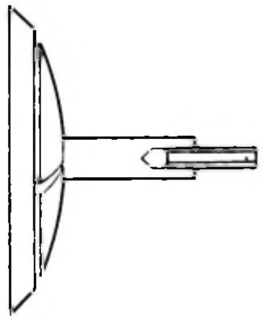
408 Polishing the exit locking face



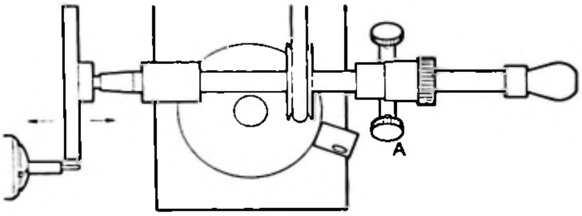
409 Tool for rough-shaping locking stones

Semi-Circular Locking Stone

Make the stone square using the tool shown in Fig 357. Then set the stone on edge, as in Fig 409, and make octagonal. Fit the stone with shellac into a brass rod in the lathe, as in Fig 410, and make the stone round with the edge of the smoothing mill fitted to the boring



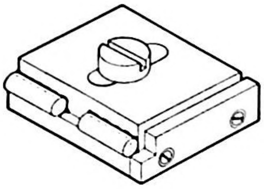
410 Octagonal pin set in brass rod



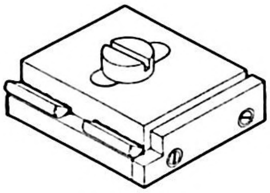
411 Polishing the pin cylindrical

spindle, as in Fig **411**. Keep a light pressure on the mill and use the stop screw *A* to prevent the mill following the stone and making it oval. When reduced to the required diameter, grip the stone close to the rod with the brass tweezers and break it off.

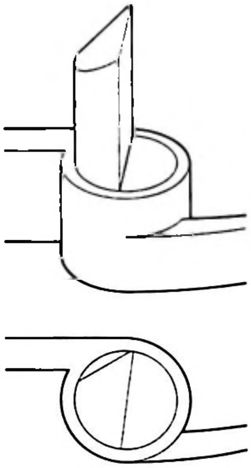
Cut the locking face on the tool, as shown in Fig **412**, and relieve the locking corner, as in Fig **413**. Lightly touch the locking exit corner on the wood mill to relieve any sharpness that would cut the escape wheel. Fig **414** shows the finished stone with the top angled back from the locking face by means of the tool shown in Fig **405**.



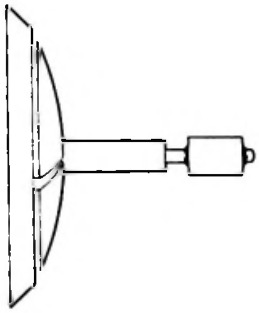
412 Tool for polishing the locking faces



413 Relieving the locking corner



414 Finished stone with sloping end

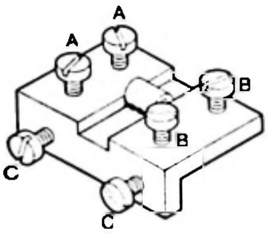


415 Duplex locking stone ready for polishing

Duplex Resting Stone

Make an octagonal pin as described for the detent locking stone. Fit it into a drilling in a brass rod in the headstock and pierce with a tool turned to the diameter of the balance staff. Replace the brass rod in the headstock with a blued-steel rod of about 1 mm diameter. Reduce the end of the rod and cement the stone into position, as shown in Fig **415**. Make cylindrical with the smoothing mill, as in Fig **411**, and finish with the fine finishing mill. Use the stop screw to prevent the mill following the surface of the stone and making it oval.

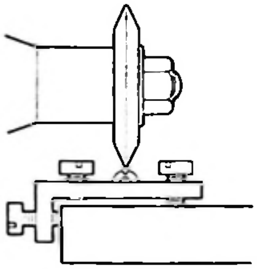
Fit a small V-edged mill into the headstock. An included angle of 30° is suitable for this slotting mill. Cement the jewel into the locating groove of the adjustable plate, as in Fig **416**. Raise the table



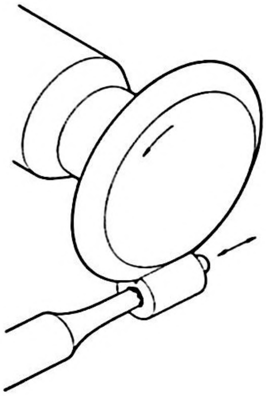
416 Tool for grooving the shell

and align it carefully with the mill so that the jewel in the plate is directly beneath the ridge of the mill. Use the screws *CC* to complete the final adjustment made with the ridge of the mill just touching the apex of the stone. Turn the screws *A* to raise the stone into the path of the mill charged with fine cutting paste. Gently pass the stone beneath the mill which must revolve against the direction of travel of the stone. This motion will cut a shallow, tapered groove in the stone. Now turn the screws *B* to raise the other end of the plate and reverse the motions. The groove will now be parallel but the process will need to be repeated several times raising each end minutely at each pass, until the full depth of groove is achieved, as in Fig **417**. Raising the stone at each end by small degrees will prevent the ridge of the mill meeting the face of the stone and becoming deformed before the groove is to full depth. Finish the groove on a wood or ivory mill with fine finishing paste while the stone is cemented to a length of wire, as in Fig **418**.

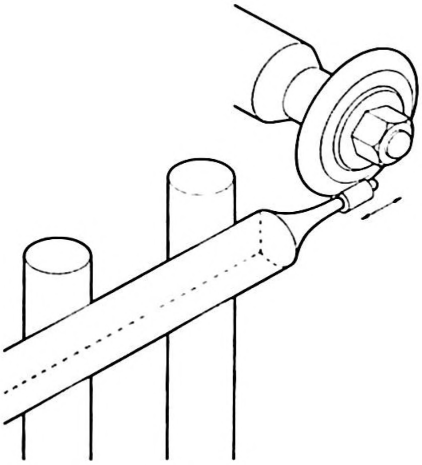
The groove can be cut much more quickly if held by hand with the wire resting against two table posts, as in Fig **419**, but this method requires some skill if a clean, neat finish is to be achieved.



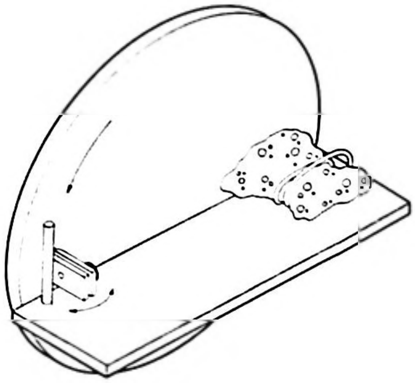
417 Cutting the groove



418 Polishing the groove



419 Hand method of cutting the groove

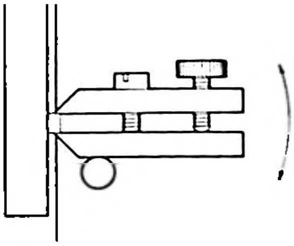


420 Curving the surface of the stone

To Curve Surfaces

The visible sides of pallet stones, impulse pallets, etc., can be curved quite simply by holding them in the clamp used as in Figs **420** and **421**. The curve, obtained with the fine finishing mill, and finally with the ivory mill adds considerably to the final appearance of the stone.

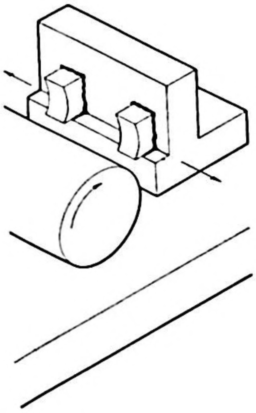
To form curved locking faces and impulse faces as used by Breguet, extra mills and carriers are required. For internal curves, turn a brass rod in the lathe to the required diameter. For a lever stone this would be a circle struck from the pallet-staff centre. Shape the stones to the required size on the tool, as in Fig **401**. Cement into

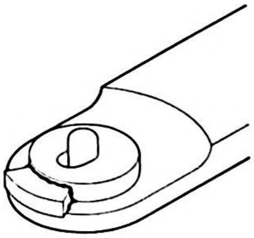


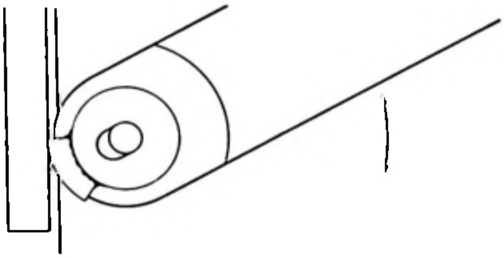
421 Detail of curving the surface

a corner of a holder at the height of the turned rod, as in Fig **422**. Charge the rod with smoothing paste and press the stones into contact as the holder is moved to and fro along the rod. Finish with a second rod of the same diameter and fine finishing paste.

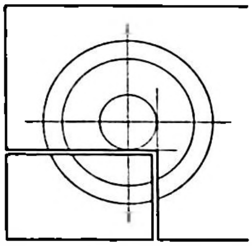
To curve the outer edge, turn a boss on a flat brass plate to the required diameter – this will also be found from the pallet-staff centre. File away one edge and make an elongated hole at the centre of the raised boss. Fig **423** shows the plate with the stone cemented to the edge ready for milling. Pivot the plate loosely on a pin in the table and with the smoothing mill bring the stone to shape while pivoting it around the pin, as in Fig **424**. The elongated hole will allow sufficient freedom to hold the stone in contact with the mill while restricting the cutting to an arc of a circle. Bring the stone to the correct width by adjusting the table relative to the mill face.

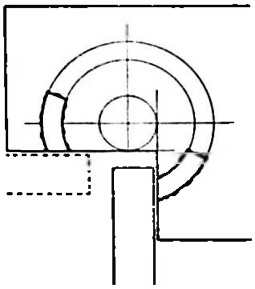

422 Tool for shaping circular locking stones

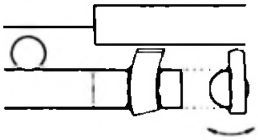

423 Tool for shaping circular locking stones


424 Detail of shaping the curve

The impulse planes will be tangents to a circle centred at the pallet staff. Draw the locking circles on a brass plate and mark off the impulse planes. Cut away the unwanted metal carefully up to the tangents, as shown in Fig **425**. Cement the stones to the plate with the curves exactly up to the circular lines, as in Fig **426**, and cut the impulse planes with the smoothing mill almost up to the brass. Finish with the fine finishing mill just touching the edges of the brass tangents.


425 Tool for impulse angles


426 Lapping the faces

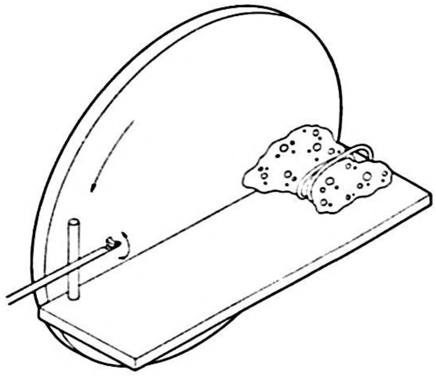

427 Curving the impulse faces

To make the planes curved, cement the stones onto a length of brass wire, as in Fig **427**, and apply to the finishing mill with a twisting motion of the wire against the post, as shown in Fig **427a**. Finish on the ivory mill using the same motion.

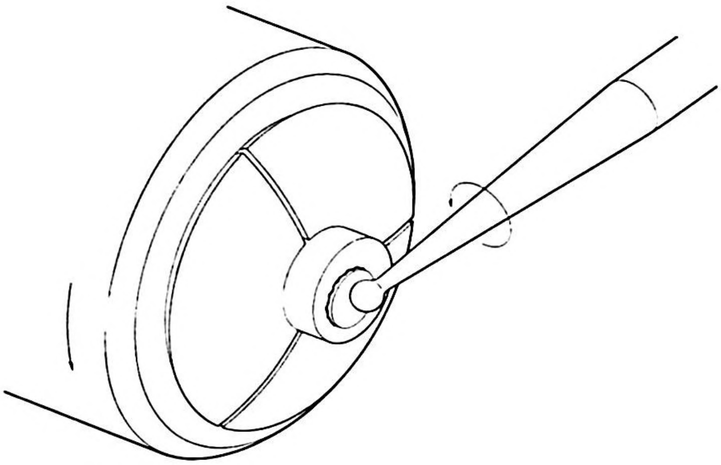
To Form the Endstone Hollows

Fit the finished endstone into an eccentric, brass holder in the lathe. Secure it with shellac and, while warm, make flat with the tailstock pad, as in Fig **384**.

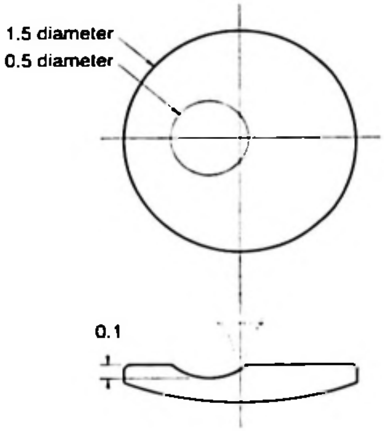
Grind the hollow with a sphere shaped at the end of a brass rod rotated in the milling quill, as shown in Fig **428**. Run the headstock spindle at about 300 rpm while the milling quill runs at about 1,000 rpm. Charge the sphere with fine polishing paste. The contra-rotation will prevent polishing marks forming in the hollows. The edge of the hollow must extend past the centre of the stone by a little more than half the pivot diameter, as in Fig **428a**.



427a Detail of curving the impulse faces



428 Grinding hollow endstones



428a Detail of hollow endstones

8

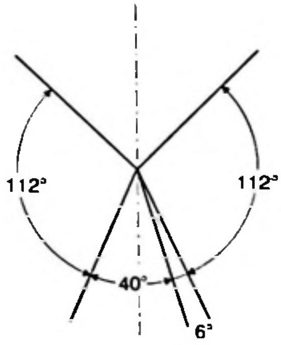
ESCAPEMENTS

General Principles

Watch escapements have an oscillating balance wheel with a spring to control the period of oscillation and an escape wheel to replenish the energy losses in the balance due to the working friction. The unlocking of the escape wheel to supply the energy impulse may be done directly at the balance axis or through an intermediate component coupled to the balance axis. The impulse may be given directly to the balance axis or through the intermediate component. Depending on the mode of operation the escapement will fall into one of two categories called 'frictional rest' and 'detached'. In both types of escapement the impulse may be delivered in one vibration of each oscillation of the balance or in both vibrations of each oscillation.

The impulse occurs during a fixed small angle of the total angle of turning, or 'total arc', of the balance vibration. The impulse angle combined with the smaller unlocking angle is called the 'escaping angle'. The total arc minus the escaping angle is the 'supplementary arc', shown in Fig 429.

When the balance is at rest the spring is unstressed or quiescent. This is the most favourable position for impulse because a small vibration will be sufficient to unlock the escapement to energize the balance against the least resistance of the spring. This is essential if the escapement is to be self-starting from the run-down condition. The quiescent point of the spring is, then, the centre line of the escaping angle.



429 Components of the balance angle:

Total arc of vibration = 270°
Unlocking angle = 6°
Impulse angle = 40°
Escaping angle = 46°
Supplementary arc = 270° − 46° = 224°

If the balance is turned through an angle of, say, 90° the spring will be stressed. When released it will return the balance to the quiescent point but the momentum of the balance will continue its rotation and wind the spring in the opposite direction until its resistance is sufficient to stop the balance and again reverse its motion. The friction of the balance pivots and absorption of energy in the flexing spring, combined with the resistance of air, will reduce the extent of the vibrations until eventually the balance will stop. If the centre of the spring terminated at the centre of motion of the balance, the diminishing vibrations would each be completed in the same time and the system would be isochronous. For practical reasons the spring must be attached to the balance at a finite radius and so different lengths of arcs are not completed in equal times. The spring can be adjusted to make the diminishing oscillations isochronous but the effect will be destroyed if an escapement is applied to maintain the motion of the balance against the frictional losses.

When a truly isochronous spring is applied to a balance the period of vibration is determined by the rate of exhaustion of balance energy. The balance cannot stop to reverse and start the next vibration until its energy is expended. Any change in the natural period of exhaustion of the energy will alter the time of vibration during the angle of change. During approach to the quiescent point a subtraction of energy will slow the first half vibration, while a subtraction after this point will quicken the half vibration. The remainder of each vibration will be performed in the natural period of the system but the total time of each oscillation will be changed. When energy is supplied to the balance before the quiescent point the first half vibration is quickened while energy applied after this point will slow the second half of the vibration. Again the remainder of each vibration will be performed in the natural period of the system but the total time of each oscillation will be changed. Subtraction of energy occurs through the unlocking of the escapement, and increase in energy during the impulse. The smaller the escaping angle the larger will be the supplementary arc which is the period of natural vibration of the total arc.

The ideal escapement would deliver the impulse instantaneously at the centre line so that the supplementary arc is equal to the total arc and errors from the escapement would not arise. The inertia of the components of the escapement and the necessity for secure lockings make this impossible. The escaping angle must be a compromise between the mechanical requirements and the adjustment available to counter their effects.

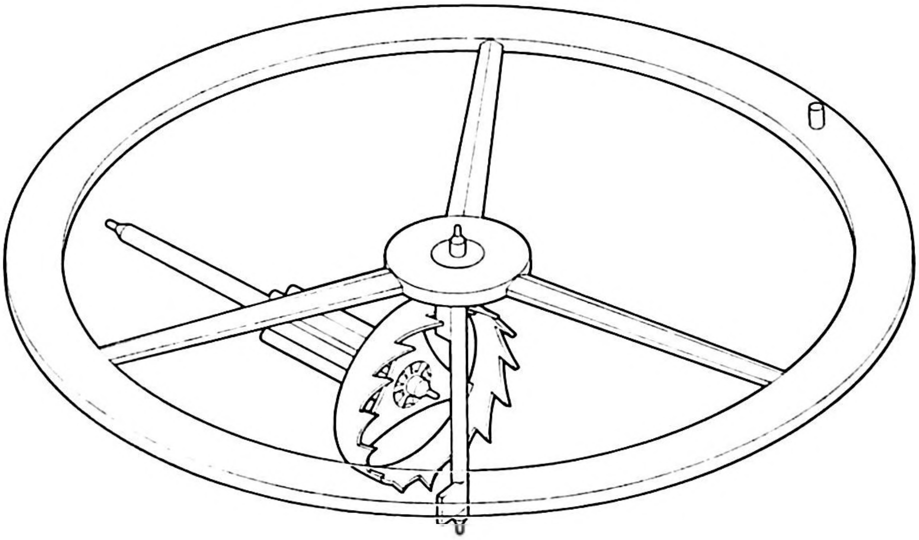
Consider the two basic categories of escapement – frictional rest and detached. In frictional rest escapements the escape wheel, after giving impulse, is locked on some part of the balance axis during the supplementary arc. The balance is never free of the subtraction of power caused by the friction, and the period of oscillation is not constant. It may be thought that since the supplementary arc occurs equally either side of the centre line, then the effects would cancel each other. This is partially true but the friction is not constant and can vary daily or seasonally with effects of temperature on the mainspring force and the condition of the oil at the friction surfaces.

In detached escapements the escape wheel is locked free of the balance axis by an additional component which is in contact with the balance only during the escaping angle and sometimes for less than the whole of this angle. The balance is free to vibrate in its natural period during the supplementary arc.

Frictional rest escapements are no longer used in watches but a description of those which have contributed to the development of the portable timekeeper during the last 400 years is essential to an understanding of the requirements of the modern escapement. The desirable basic principle of the radial impulse is contained in the verge escapement while that of the tangential lock is contained in the cylinder escapement. Both escapements are primitive and neither is a successful timekeeper.

It is undesirable to lubricate the teeth of the escape wheel because the deterioration of the oil will adversely affect the stability of the timekeeping. The verge escapement does not need oil and yet its performance is generally inferior to the cylinder which does need oil. The lever escapement has a tangential impulse which is inferior to the radial impulse of the verge. It will not run without oil and yet it is capable of very close timekeeping when the oil is fresh and will out-perform the verge for many years until the oil is too dry to lubricate it.

A sound knowledge of the reasons for these apparent anomalies is essential to the success of any attempt to improve on the performance of existing escapements.



430 Verge escapement

Verge Escapement

The verge escapement, illustrated in Fig 430, is the oldest of all escapements. Its origins are unknown and it was used in tower and table clocks before the latter were reduced sufficiently to be conveniently carried as watches. It has only two components: the escape wheel, or crown wheel as suggested by its shape, and the verge or balance axis. This carries two pallets set at an included angle of about 100° towards the escape wheel. As the upper pallet is turned aside by the tooth in engagement the lower pallet will turn into the path of the lower tooth. The impulse is completed when the upper tooth leaves the tip of the upper pallet and the lower tooth has dropped on to the root of the lower pallet. The momentum of the balance prevents its immediate reversal and in continuing the vibration the escape wheel is recoiled until the balance energy is exhausted. During the return vibration the balance is turned by the lower pallet until the tooth leaves the tip and a following tooth falls on to the upper pallet to complete the oscillation with the recoil. The escape wheel is never at rest and 'frictional arrest' might be a more fitting description than 'frictional rest'.

Early verge escapements worked without a balance spring and this is the only escapement that can do so. During the recoil the whole train is reversed so that the pinions are driving the wheels. Since the teeth were cut by hand and eye without knowledge of the most suitable shape, the train offered considerable variation in resistance to the recoil with directly variable effects on the extent and time of vibration of the balance. The earliest escapements had large, slowly vibrating balances in an attempt to gain some dominion over the power variations. By the late sixteenth century these had been much reduced in diameter and vibration period, presumably because a faster vibration is less easily stopped by sudden movements of the watch. Until the application of the balance spring in the 1670s, the timekeeping of the verge was extremely vague with variations of up to about half an hour per day. With spring, and improved wheel cutting for the train, the rate improved to within five minutes per day. No further significant improvements were made, although the escapement continued in steadily declining use until the early twentieth century.

The best angle of opening of the pallets has been found to be 100°. Less than this reduces the balance amplitude for a proportionately greater recoil. More than 100° causes excessive friction at the pivots because the verge must be set closer to the escape wheel. This is a frequent cause of setting in late eighteenth-century verges when the angle was sometimes increased in excess of 110° to increase the balance amplitude for a relatively reduced recoil. This can be rectified by closing the pallets to 100° and drawing the escape wheel away from the verge. Adjustment is provided for deepening the escape wheel as also for setting in beat so that the drop is equal on both pallets. This is done by moving the escape-wheel pivot in the direction of the tooth with the greatest drop on to the face of the impulse pallet.

With or without a balance spring the balance vibrations can be made faster or slower by altering the depth of engagement of the crown wheel with the verge. Setting the wheel closer will slow the vibrations and vice versa.

Without a balance spring the timekeeping can be very erratic and is entirely at the mercy of power fluctuations in the train. The fastest vibrations of the balance occur when the engagement of the wheel teeth and pinion leaves of the whole train coincide at the pitch centres of each pair. Any other position of any or all of the pairs will cause a variable diminution of power and consequent change in the vibrations of the balance. The fast vibration with full power will be quickly exhausted by the commensurate power of the rocoil. This will make the whole vibration fast since both impulse before the centre line and subtraction after the centre line quickens. When the power reduces, the quantity of the impulse is reduced and the half vibration is slower. The subtraction is also reduced and the balance can turn further before the inertia is exhausted, and so the second half of the vibration is also slower. The power fluctuations are continuous and varied and the rate is wholly dictated by them.

Early pre-spring verge watches are indifferent timekeepers but there is much charm in their erratic progress which endows them with a curious kind of humanity. The application of the balance spring in the 1680s improved matters by overcoming the inertia of the balance to quicken the lower power vibrations to the centre line and subtracting greater energy from the balance during the recoil to quicken after the centre line.

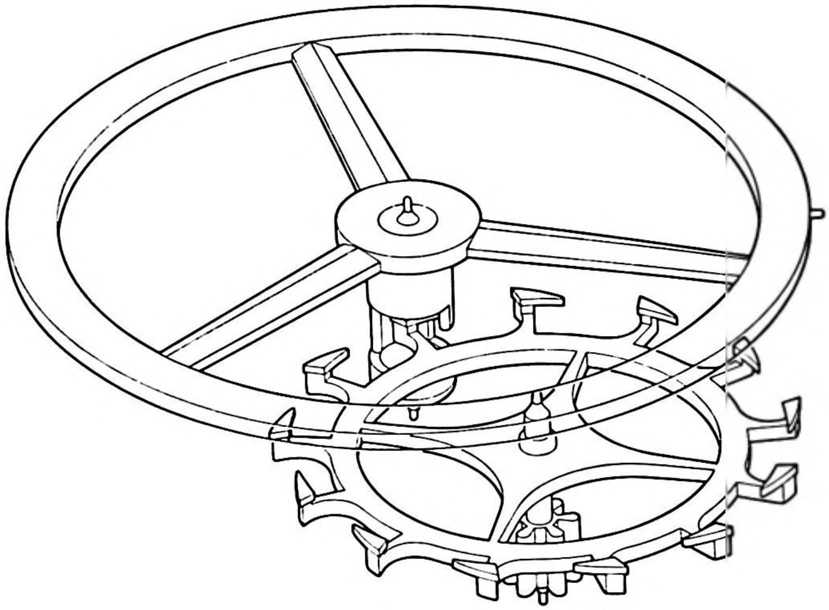
The high-power vibrations are controlled by the inertia of the balance wheel but if the maximum power is exceeded the watch will gain. For this reason a broken mainspring should be replaced with a spring of the same power. Where this is not possible some control can be had by changing the depth of the crown wheel. This method was used in the earliest iron watches by bending the balance cock. The effect available for a verge with balance spring is less than for a pre-spring watch. If deepened to excess both types may stop in a low-power fluctuation. The spring watch is more likely to stop because more power is needed to wind the balance spring during the recoil. For this reason sprung verge watches need stronger mainsprings than unsprung watches.

The unsprung escapement can be adjusted over a wider range to compensate for a greater loss. However, adjusting such watches is not always entirely satisfactory for, if the watch is held with the crown wheel above the verge, the low-power impulses may allow the wheel to fall back into deeper engagement. The verge escapement was used in watches from about 1500 to 1900. By the end of the eighteenth century it had become thoroughly antiquated and continued in use only because of the ease with which it could be made in small workshops with simple equipment. It has no place in modern watchmaking.

Cylinder Escapement

The cylinder escapement, as illustrated in Fig 431, was invented by George Graham in the early eighteenth century. The impulse is provided by the raised inclines of the escape wheel. Their tips rest alternately on the outer and inner surfaces of the semicircular part of the cylinder forming the balance axis.

During the supplementary arc the tip of the tooth is locked stationary in frictional contact with the cylinder. This is an improvement on the verge for the train is not reversed but the radius of the locking is equal to the radius of the impulse and the frictional losses are higher than the verge. Extra power applied to the verge escapement will shorten the vibration period. The increased friction of extra power applied to the cylinder escapement will lengthen the vibration period.

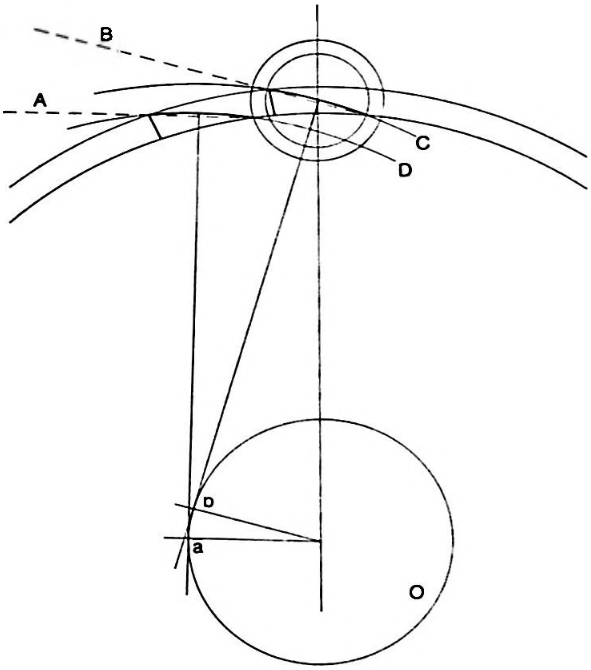


431 Cylinder escapement

Early cylinder wheels had straight inclines to the teeth. The inertia of the wheel, when unlocked by the cylinder travelling at maximum velocity, needed a strong mainspring to accelerate the inclines into contact with the impulse lip of the cylinder. The leading part of the incline was not quick enough to deliver any impulse and the last quarter, by reason of the relative change in angle, was too fierce. Curving the inclines improved the action and, by making the lift more uniform, as shown in Fig 432, allowed the use of a weaker mainspring. The later use of steel escape wheels helped further to reduce wear to the cylinder which was finally eliminated by a cylinder cut from sapphire.

The proportions of the escapement were improved by Breguet who devised his own form of ruby cylinder in about 1794. As a timekeeper the early cylinder escapement was not very much better than the verge, but could maintain a rate of about two minutes per day. In terms of reliability or running without need of servicing, the verge was superior and its robustness made it nearly indestructible. In Breguet's hands the cylinder escapement was endowed with the same qualities, and with the aid of his temperature compensation curb, its rate was improved to about one minute per day.

The essential proportions of the escapement are contained in the ratio of cylinder to balance-wheel diameter. The ratio of cylinder to escape-wheel diameter is fixed by the number of teeth in the wheel and the numbers 13 to 15 seem largely to have been determined by the space available in the watch. For a given-sized tooth, if the number were increased, the wheel would be larger in diameter, and would touch the fourth wheel pinion. For a given-sized wheel,



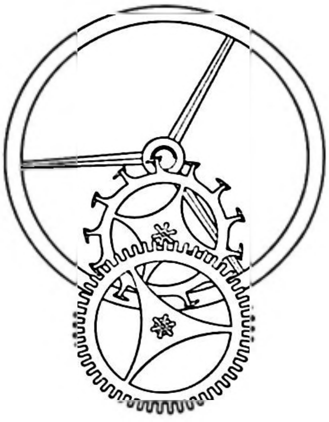
432 Cylinder escapement impulse curves:

Lines *A* and *B* show the change in lift angle that occurs during impulse with straight inclines. The curves *C* and *D*, struck from tangents to *O*, produce uniform lift during impulse. The diameter of *O* is equal to twice the cylinder diameter.

increasing the number would necessitate a smaller cylinder; this would be more fragile and need a lighter balance with consequent loss of inertia. Reducing the number of teeth would leave the cylinder too large. If the wheel diameter were reduced to compensate, the balance would need to be reduced to avoid the fourth pinion and, again, its inertia would be reduced.

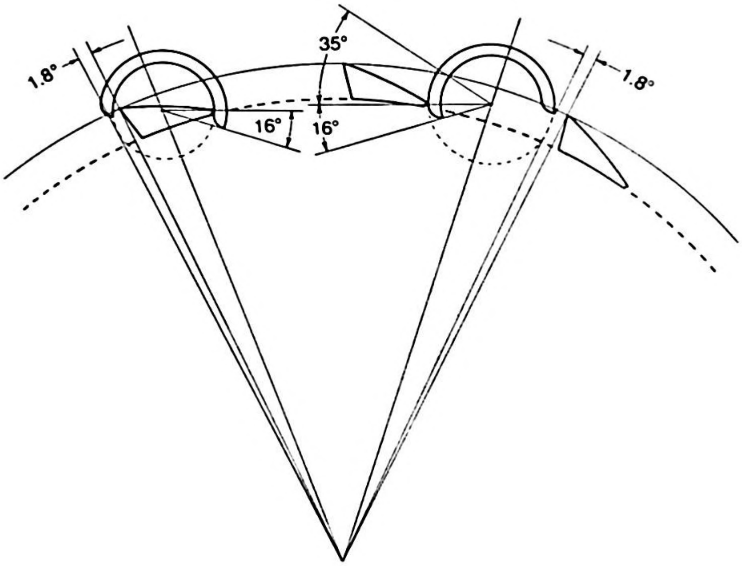
The fourth wheel clearly has some influence on the proportions of the escapement and this is simply defined. The escape wheel cannot be larger than the fourth wheel minus one and a quarter times the fourth pinion radius, and the balance can be a little larger than twice the diameter of the escape wheel. The ratio of cylinder to balance diameter will then be between 12 and 15:1, as in Fig 433.

This simple arrangement was used by Breguet in his best cylinder watches and produces a very satisfying result. The cylinder is large enough in radius to be self-starting from the run-down condition and small enough to avoid setting by friction on the walls if the balance is stopped and released again to start. This cannot be achieved without considering also the proportions of the balance. If too heavy it will need a strong balance spring to reach the required number of vibrations. The escape wheel would then be unable to turn the balance, from stationary, against the resistance of the balance spring. If the balance is too light the weaker balance spring will be unable to turn the balance against the friction of the unlocking and, again, the escapement would not start.



433 Proportions of the cylinder escapement

The exact dimensions of the components of any escapement depend upon the space available and so it would not be useful to make suggestions. The actual work of determining the best proportions for differently sized watches was done by practical construction and observation between 1760 and 1800. In the extremely unlikely event of any reader wishing to make a cylinder watch he could do no better than study the work of the best Swiss and French makers of the early nineteenth century. Textbooks usually describe the cylinder escapement in precise terms. Figures of 10° of locking and 1° of drop are usually given. Examination of good hand-made examples shows them to be more coarsely constructed. Fig **434**, taken from a ruby cylinder escapement by Breguet, has 1.8° of drop and 16° of locking for an escaping angle of 51°. This would seem to be very inefficient but the balance turns through 126° to give a supplementary arc of 75°. Banking occurs at 155° and so the action cannot safely be more vigorous. The escapement is self-starting and will restart if stopped. It is completely reliable and was last cleaned about ten years ago. Its rate has remained within two minutes per day throughout the ten years and shows no sign of deteriorating. The balance pivots are 0.1 mm diameter and, although without any sign of wear, are a slack fit in their jewel holes. Clearly the precision work of the factories mass producing cylinders in the late nineteenth and early twentieth centuries was no match for Breguet's intuitive understanding of the requirements of Graham's escapement.



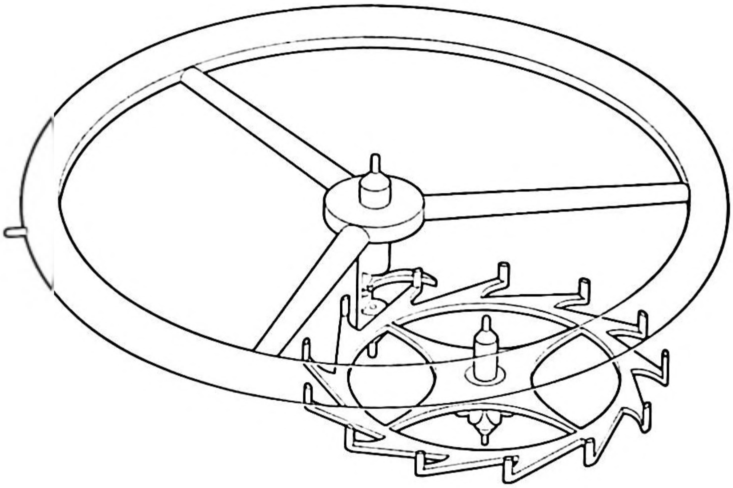
434 Cylinder escapement lift and lock angles

The continuous friction of the tooth on the cylinder walls during the supplementary arc places the cylinder escapement in the frictional rest category. The friction occurs at the same radius as the impulse and acts as a brake on the surfaces of the cylinder. This has the curious advantage of improving the isochronism of steel cylinder escapements. An increase in the power of the impulse will bring an increase in resting friction to prevent the arc changing.

This is not so pronounced with a ruby cylinder in which the resting friction is much reduced.

The amount of impulse that will occur before the centre line is dependent on the depth of the locking. The greater part will take place after the centre line and the escapement will lose for a diminution of supplementary arc.

The resting friction of the locking makes it impossible to get a precise rate from the cylinder but Ferdinand Berthoud, who thought very highly of his own work, found occasion to praise his weight-driven marine timekeepers with ruby cylinder escapements.

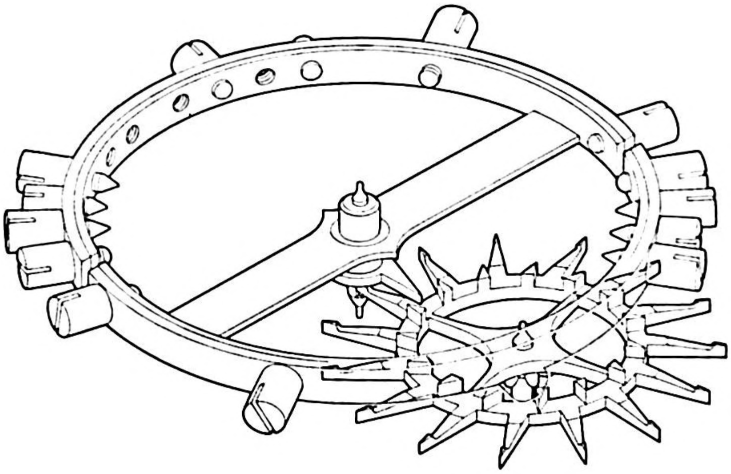


435 Virgule escapement

Duplex Escapement

The duplex escapement is a derivation of the virgule escapement.

The virgule, illustrated in Fig 435, is a single impulse frictional rest escapement with impulse and locking at the largest radius of the wheel. The duplex, illustrated in Fig 436, has the advantage that

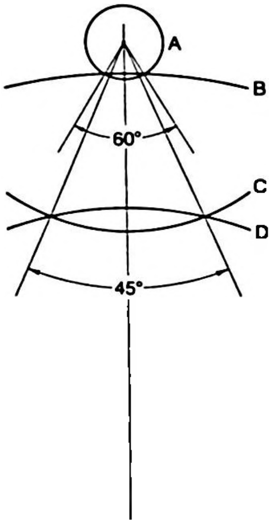


436 Duplex escapement

the locking and impulse are effected at more advantageous radii. The long, locking tooth rests on a ruby cylinder with a notch cut axially in its surface to allow the tooth to pass ready for impulse.

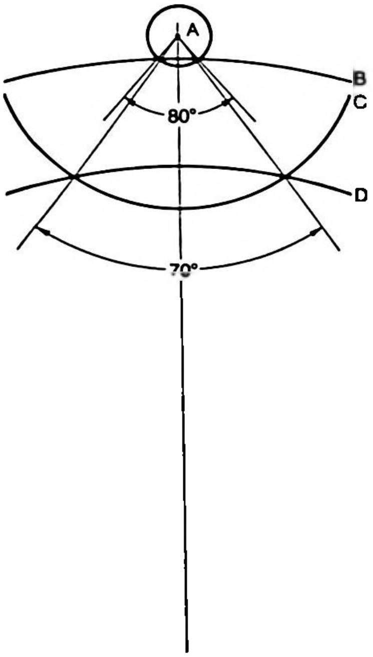
During the passage a small impulse is given by the tip of the tooth as it presses against the departing side of the notch. When the tooth is free the main impulse is given to the pallet by the teeth of shorter radii. Sometimes, as in the original conception, there are two separate wheels. Later watches by English makers from about 1790 have single wheels with two sets of teeth. A small drop occurs between the completion of the small impulse and the commencement of the main impulse. A second drop occurs on completion of the main impulse.

Both impulses occur in one vibration only. The return vibration is idle and the escape wheel is disturbed only slightly by the return passage of the notch. This is the principal disadvantage of the escapement which, while not sufficiently precise in its rate to warrant the extra care of use and handling accorded to the chronometer, will sometimes set in ordinary use.



437 Breguet's proportions for the duplex escapement

Its construction requires most careful and skilled workmanship if it is to work well. The intersection of the roller and locking teeth is shallow and tripping will occur if the pivots are slack in the jewel holes. The pressures of the action of the escapement are high and all holes should be jewelled to prevent wear to the pivots. If the escapement knocks when the balance axis is vertically above the escape wheel it may be due to worn pivots allowing the balance to come too close to the wheel. This can also occur through an incorrectly sized locking roller allowing the pallet to strike an impulse tooth. Duplex wheels are sometimes seen with the locking teeth bent to overcome this fault. The only true solution is a new roller. If the error is very small it can be corrected by slightly shortening the impulse pallet.



438 Jurgensen's proportions for the duplex escapement

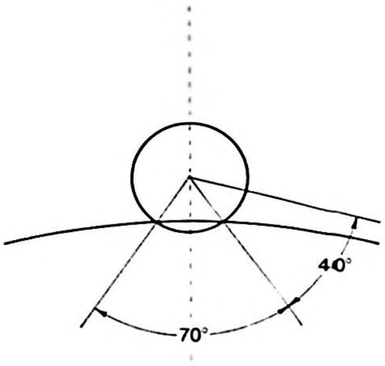
The best proportion of the components seems to depend on the fancy of the constructor. No two individually made watches have the same component proportions but the watches exhibit no difference in performance. Taking three high-grade examples by D. W. Morice of London, A. L. Breguet of Paris and J. Jürgensen of Copenhagen, all made in the nineteenth century, the following proportions are found:

A = locking-roller diameter
B = locking-teeth diameter
C = impulse-pallet diameter
D = impulse-teeth diameter

	Morice	*Breguet* (Fig 437)	*Jürgensen* (Fig 438)
$\frac{B}{A}$	16:1	12.5:1	18:1
$\frac{D}{C}$	2.2:1	1.5:1	2.6:1
$\frac{B}{D}$	1.39:1	1.45:1	1.19:1

It would seem that the duplex is indifferent to proportions and that its advantage when compared to the cylinder depends basically on the very small frictional radius of the locking.

To prevent the escapement setting, the small impulse must occur equally either side of the centre line with the quiescent point of the spring set at the centre line. This will ensure escaping at amplitudes only slightly in excess of the escaping angle. The large impulse will occur after the centre line. Fig **439** shows the usual, large unlocking angle for the long teeth and the continuing angle for the impulse of the short teeth. This is the inherent weakness of the duplex for the total escaping angle is in excess of 100° of which only some 35° are before the centre line. Thus the minimum safe escaping angle is above 75°. If the balance vibration exceeds 180° the power required will cause wear to the impulse teeth and pivots and the escapement will become unreliable. Allowing a vibration of 180° leaves only 105° of supplementary arc. This is not enough for everyday wear and can cause a set that needs a vigorous shake to restart the watch.

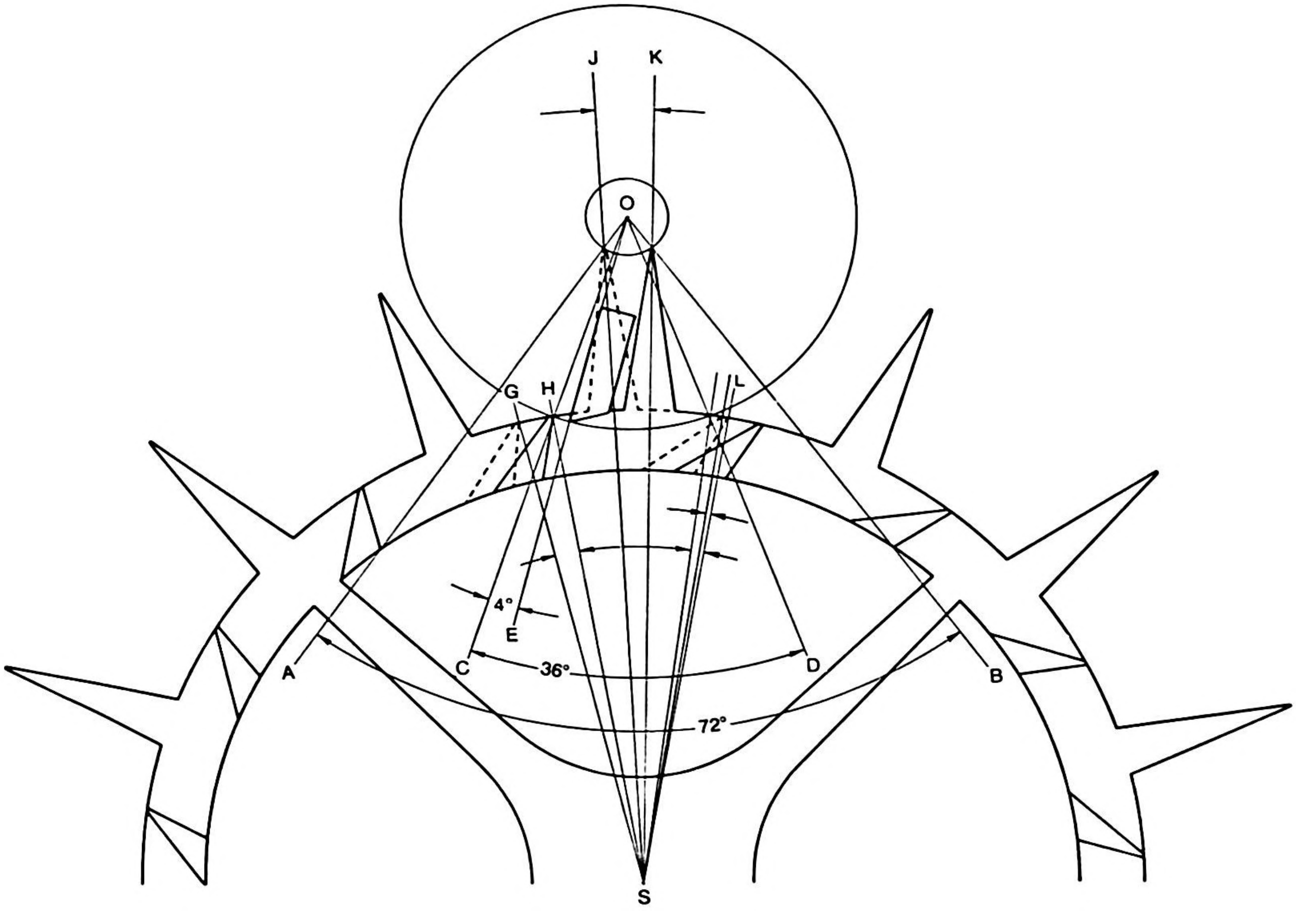


439 Duplex average escaping angle

The escapement needs the lowest possible ratio between the locking-teeth diameter and the roller. In the examples given the greatest difference in this ratio occurs between Breguet and Jürgensen. Fig **437** shows the advantage gained by Breguet with his lower ratio. His unlocking angle is 60°, while in Fig **438**, showing Jürgensen's ratio, the angle is 80°. Breguet also has a lower ratio for the impulse teeth to pallet diameters and his impulse angle is 45° while Jürgensen's higher ratio gives a greater angle of 70°. Breguet's escaping angle shows a difference of 25° of escaping angle in favour of the supplementary arc.

The difference is not wholly in Breguet's favour for the friction of his roller is greater and the reduced impulse angle, with its relatively larger drops, combines with this to demand a greater power of impulse. Jürgensen no doubt preferred the gentler system and was prepared to instruct his purchaser in the proper use of the watch. Breguet knew well that clients never use watches according to the maker's instructions and he preferred to rely on his experience. Neither escapement is better than the other. Both work well and vigorously and show little sign of wear. This is a tribute to their makers' ability, for a badly made duplex will give trouble and will soon be destroyed by the botch repairer. The escapement by Morice is in the best traditions of the English compromise, falling neatly between the two extremes.

Development of the escapement ceased by the middle of the nineteenth century. The later examples have lower $\frac{D}{C}$ ratios than Breguet's but the inherent disadvantage of the relatively large escaping angle and single impulse remain. Fig **440** shows a late escapement of similar proportions to the work of James McCabe, a distinguished nineteenth-century maker. The dashed lines show the position of the components at rest and the solid lines the position immediately prior to the main impulse. The small impulse or unlocking angle is 72° and the impulse angle 36°. Note that the intersection of the roller and locking teeth is only 0.05 mm and no



440 19th-century duplex proportions:

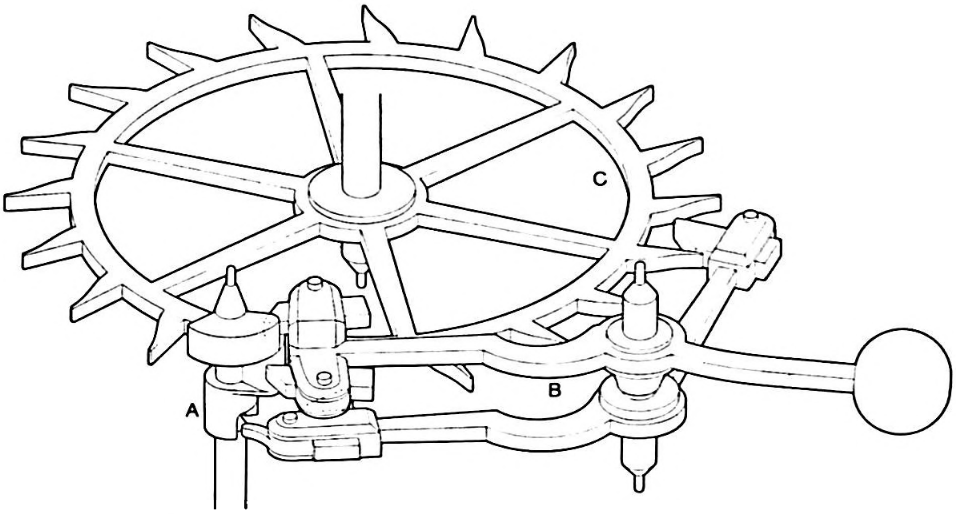
Angle *AOB* is the small impulse of unlocking
Angle *COD–COE* is the large impulse
Angle *GSH* = *JSK* = wheel advance for small impulse
Angle *HSL* = wheel advance including drop and tooth width for large impulse

tolerances for eccentricity of the components can be allowed.

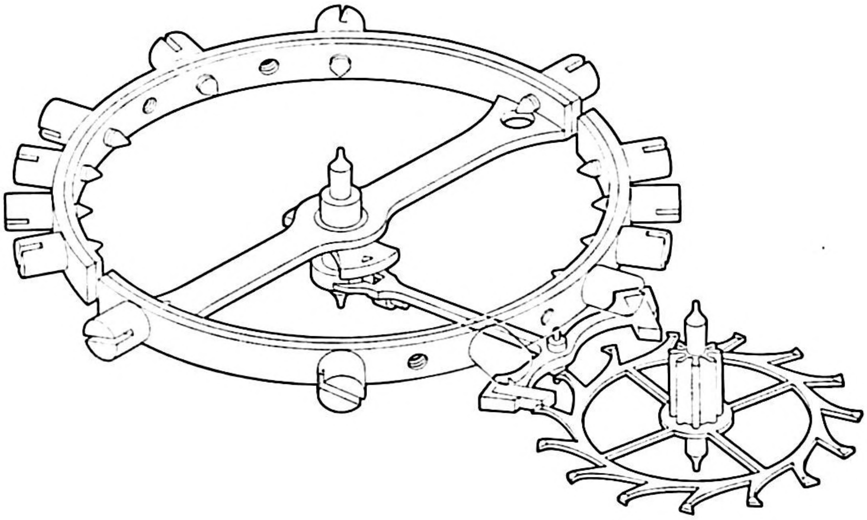
A form of escapement known as the Chinese duplex has double-locking teeth. Two passing vibrations are required for each impulse vibration. When used with a wheel train of 14,000 vibrations the escapement will indicate one large advancement each second. This system was once held in high esteem by the Chinese who despised crawling seconds hands on their watches. Such escapements are bad timekeepers, but doubtless the Chinese had sufficient tranquillity of mind not to be concerned.

Lever Escapement

The lever escapement was invented in 1754 by Thomas Mudge. He made the first watch with the escapement in 1769 for Queen Charlotte, and the watch remains in the Royal Collection. The escapement is illustrated in Fig **441** and comprises a roller *A* fitted to the balance axis, a lever *B* with attached pallets for locking and impulse, and an escape wheel C with radial teeth to lift the pallets.



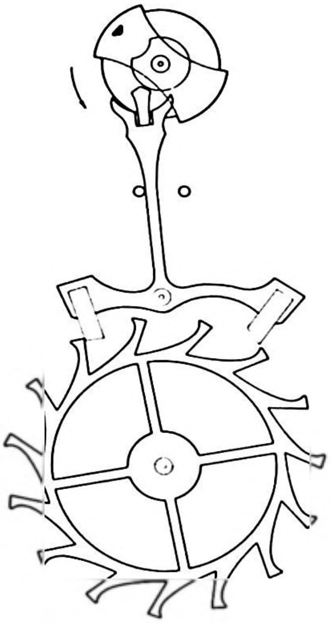
441 Lever escapement by Thomas Mudge, 1769



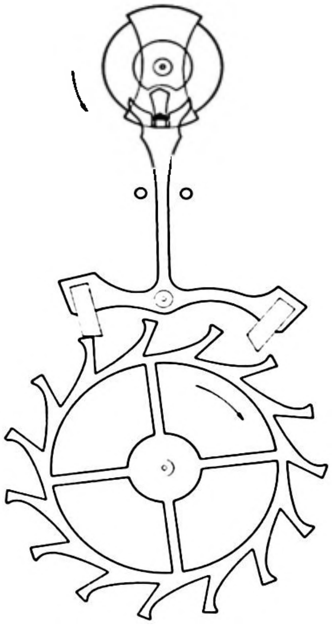
442 20th-century lever escapement

The three components are pitched in a triangle but may be pitched in any way that allows the same functional engagement of the components. This is a detached escapement and the escape wheel, after delivering the impulse via the intermediate lever, is locked free of the balance during the supplementary arc.

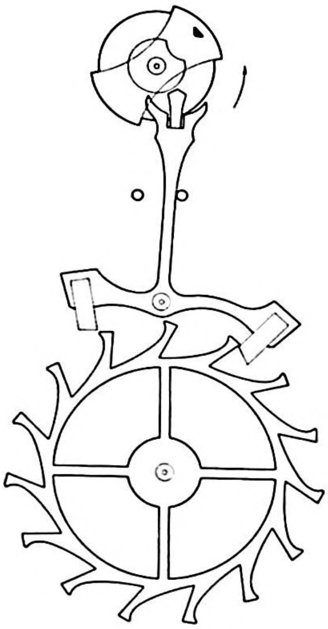
Fig **442** illustrates a modern form of the escapement with the components pitched in a straight line. The action occurs equally on each side of an imaginary line drawn through the pivot centres. This is the centre line of the escapement. Figs **443**, **a** to **d**, illustrate the action of the components.



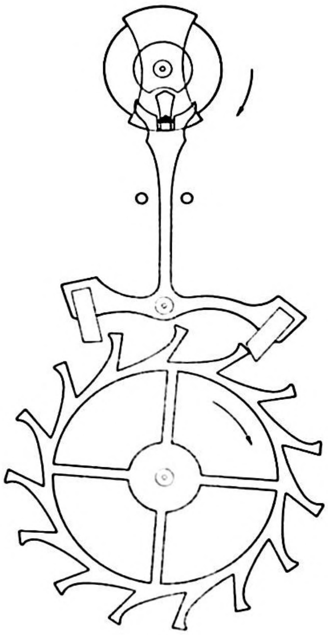
443a Tooth locked on entry pallet



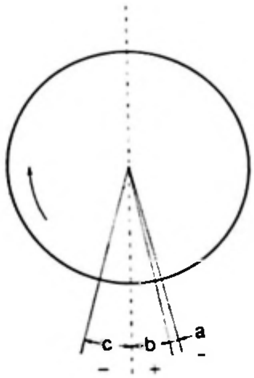
443d Impulse to balance from entry pallet incline



443c Tooth locked on exit pallet



443d Impulse to balance from exit pallet incline



444 Lever escapement error

In Fig 443a the balance is turning anticlockwise in the supplementary arc with a tooth of the escape wheel locked on the entry pallet. In Fig 443b the impulse pin has entered the fork and turned the lever to unlock the tooth which is free to advance along the lifting incline to impulse the balance through the fork and impulse pin. In Fig 443c the impulse is completed and a tooth is now locked on the exit pallet. The balance continues to turn anticlockwise until its energy is exhausted in the supplementary arc. In Fig **443d** the balance returns in a clockwise direction to unlock the tooth and receive impulse from the exit pallet.

Note that as the lever crosses the centre line the guard pin passes through the crescent cut in the safety roller. The guard pin and safety roller combine to prevent the escapement unlocking except during the escaping angle.

The locking faces of the pallets are set at a small angle to the radial tip of the wheel teeth to draw the pallets hard on to the banking pins. If the position of the lever is disturbed during the supplementary arc the guard pin will prevent unlocking and the draw angle will pull the guard pin away from the roller.

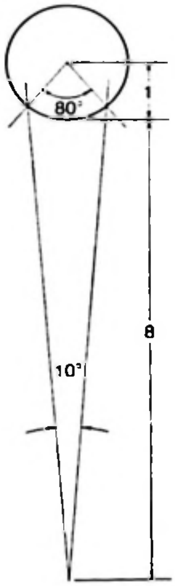
Escaping Angle

Fig **444** shows the effect of different parts of the action in terms of escapement error. The unlocking angle *a* occurs before the centre line and is a subtraction of energy resulting in a loss. The angle *b* is the impulse before the centre line and will cause a gain. The angle *c* is the greater part of the impulse given after the centre line and will cause a loss. The extent of the angles will vary according to the proportions of the escapement but the greater part of the impulse will always occur after the centre line. It follows that the natural error of the lever escapement produces a loss and the escaping angle must be kept small to reduce its effect on change of balance amplitude. The escaping angle is the product of the lever to roller ratio and the lever angle.

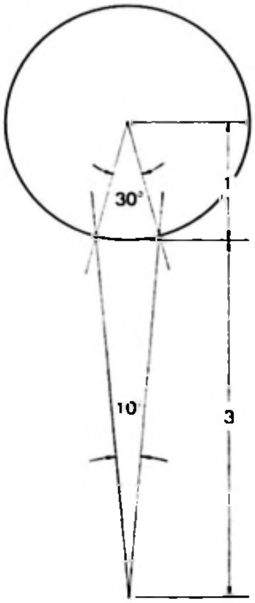
The diagram in Fig **445a** shows the approximate angles of Mudge's escapement as compared to the angles of a modern escapement, shown in Fig **445b**. Both have a lever angle of 10°. Mudge's has a lever roller ratio of 8:1 giving an escaping angle of 80°. The modern arrangement has a ratio of 3:1 giving an angle of 30°. This is much nearer the ideal of instantaneous impulse at the centre line which would leave the whole of the supplementary arc free to vibrate in its natural period, without influence from the escapement error.

The angle of 30° could be reduced still further by reducing the lever angle or enlarging the diameter of the roller. Unfortunately, the inertia of the components, combined with the necessary running clearances and safe intersection of working angles, sets a limit to the possible reduction of the escaping angle. In fact, an angle below 30° can only be achieved by most careful workmanship and skilled attention to detail.

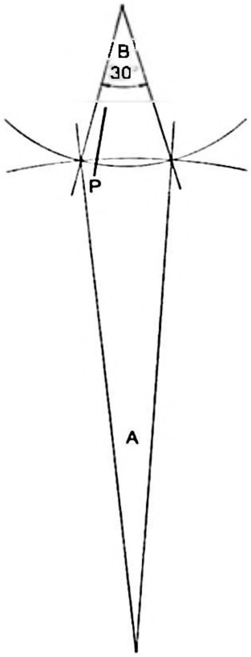
The angle of 30° is quite commonly found in Swiss watches mass produced by machine methods. The escapements are the result of experience and development undertaken during the past seventy years. The success of this work is underlined by the remarkable rates obtained by the escapements in competitive trials. While it is not suggested that the escapement cannot be further improved, it is probable that the limit of efficiency in the interrelated action of the components has been reached. An alteration to the action of one aspect of the escapement cannot be made without consideration of its effect on the action as a whole.



445a Proportions of Mudge's escapement



445b Proportions of modern escapement



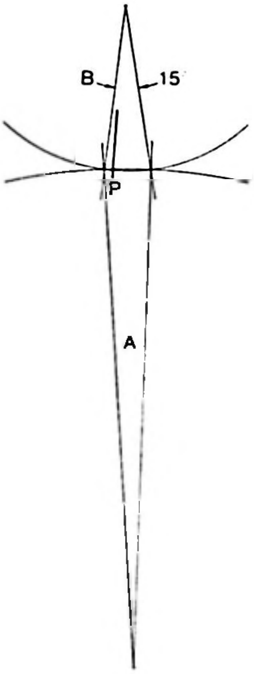
446a Intersection of roller pin and fork

In considering the escaping angle it should be noted that a decrease in angle is accompanied by a proportional reduction of the time available to complete the action. In reducing the angle from the 80° of Mudge's escapement, shown in Fig **445a** to the 30° of that shown in Fig **445b** the escape wheel must accelerate 2.3 times faster to complete the lift. During the unlocking the recoil of the escape wheel due to the draw angle will be 2.3 times faster and the inertia of the wheel will increase as the square of the speed. For excessively small escaping angles a stronger mainspring would be required to overcome the inertia of the wheel. This, combined with the high impact velocity of the components, would lead to fierce frictional pressures and wear. A further effect of the increasing locking pressures of the stronger mainspring would be a tendency for the escapement to set on the locking at low balance amplitudes.

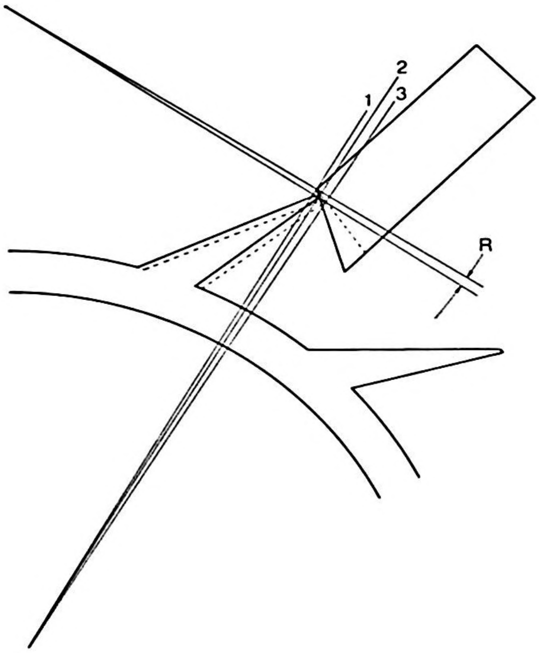
A more immediately obvious objection to a very small escaping angle is the difficulty of arranging a safe engagement of the impulse pin with the lever fork. In Fig **446a** for an angle of 30° the intersection of the arcs for the lever *A* and the impulse pin *B* is sufficient to ensure the complete engagement of the pin by the flanks of the fork. This must be so, both for unlocking at the deepest point and for the starting of impulse at *P*. For half the angle, Fig **446b**, the intersection is hardly enough for unlocking and the corner of the fork would jam on the impulse pin at *P*. With so small an intersection the running clearances of the pivots in their holes would make the action inconsistent with the watch in different positions. The escaping angle can be reduced to below 30° but it is clear that the manufacturing tolerances must be disproportionately closer.

Lever Angle

The lever angle is the angle turned by the lever between the banking pins to complete the unlocking, the lift and the run to the banking. A decrease in lever angle for a given-sized roller will produce a reduction in escaping angle. The decrease can only be achieved by a reduction in the angle of lift which will multiply the losses arising from the running clearances. An angle of 11° is usually allowed for the lever and includes the run to the banking. Fig **447** shows the dimensions of the angle. *U*, the 2.5° of unlocking, includes a 1° run from the banking. *I* is 7.5° of impulse and *R* is 1° of run to the banking. If the angle is to be reduced the angles for lock and run to the banking must remain. Less than 1.5° of locking would be unsafe and a reduction in the run to the banking would leave insufficient clearance between the guard pin and safety roller. The reduction in angle must then come from a reduction in the height of the lifting incline. A tooth will start to lift the incline at the moment unlocking is complete, but the first part of the lift is expended in taking up the running clearance of the impulse pin and pivot holes. In Fig **448** a tooth at 1 has left the locking corner and advanced along the incline to position 2 to take up the running clearance. Reducing the height of the incline will allow the tooth to advance to 3 and a greater proportion of the impulse will be lost while taking up the running clearance *R*.This increased loss of



446b Unsafe intersection of roller pin and fork



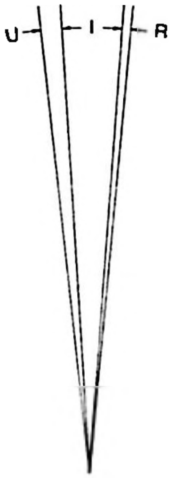
448 Minimum useful lift angle of the lever

impulse combined with the necessity for ensuring safe engagement of the impulse pin with the fork has set the minimum useful angle of the lever at 10°. This is sometimes increased to 11° to allow extra locking depth and increased run to the banking. A locking angle of 1° would be too shallow for a small watch in which the running clearances cannot be reduced in proportion to the size of the watch.

The Draw Angle

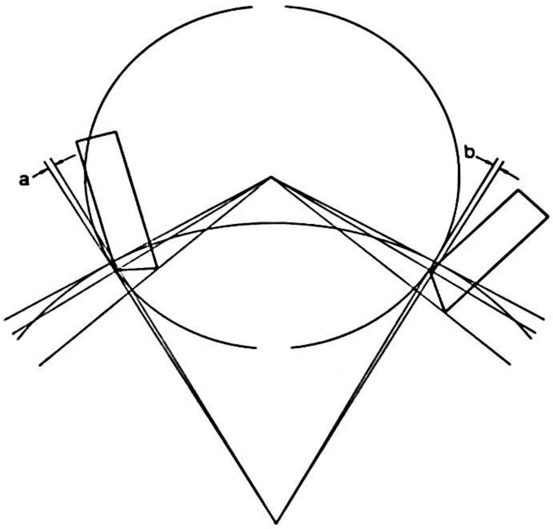
The draw angle functions during the run to the banking and allows a small advance of the escape-wheel tooth after the locking and during the run to the banking. This is effected by inclining the locking face of the pallet to the radial of the tooth tip. During the unlocking the angle of the pallet face will cause the wheel to recoil and offer resistance to the unlocking. The same resistance will apply more usefully during the supplementary arc, and the lever will be drawn back to the banking if accidentally displaced by a sudden shock to the watch. The angle of recoil imposed by the entry pallet is shown in Fig **449** at *a* for the entry pallet and *b* for the exit pallet. The arcs of motion of the corners of the pallet show that the draw increases during unlocking on the entry pallet and decreases on the exit. The recoil of the wheel against the power of the mainspring is wholly wasted energy and must be kept to a minimum.

A polished steel weight resting on a polished sapphire surface will start sliding when the surface is tipped to an angle of about 9°. This is the minimum useful angle of draw. To make the action more certain the angle of locking face is increased to 14°. To make the



447 Component parts of lever angle:

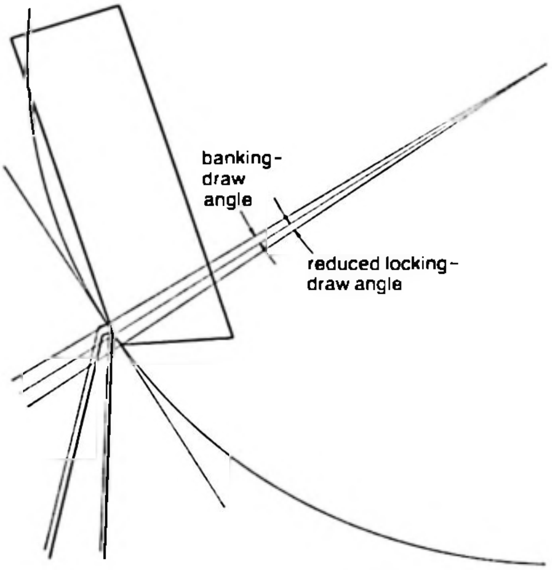
U = 2.5° unlocking angle
I = 7.5° impulse angle
R = 1° run to the banking



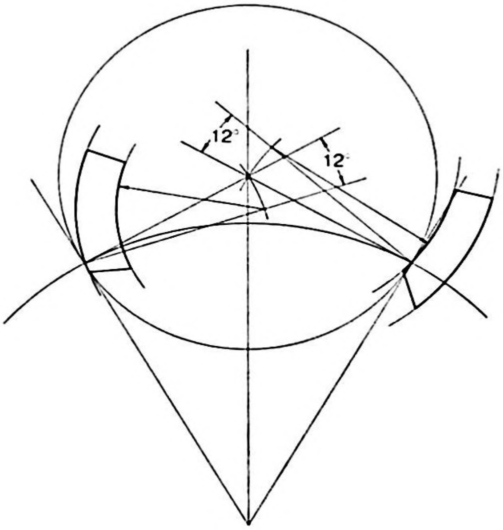
449 Angles of recoil due to the draw angle

draw more uniform the angle for the entry pallet can be reduced to 13° and, for the exit, increased to 15°. This is a convenient method used for mass produced watches. In fact, it is not necessary to increase the exit angle because the draw is useful only for the run from the banking which is the angle bounded by the banking pin and the guard pin. The unlocking angle does not need draw and so the reduction in the exit angle during unlocking is not important. The increase in the entry angle can be prevented by reshaping the locking corner of the stone, as shown in Fig 450.

The change in draw angle is proportional to the change in lever angle during the unlocking. An unlocking angle of 3° would reduce



450 Reducing the increase in the entry draw angle



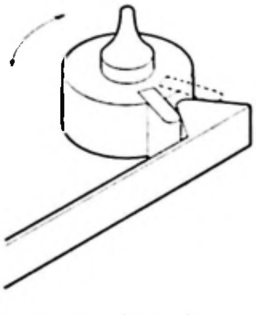
451 Constant draw locking faces

14° of draw to 11° on the exit and increase this to 17° on the entry. If the locking faces were curves struck from centres at 12° to the locking tangent, as shown in Fig 451, the draw would be equal and uniform for both pallets. This would effect a considerable saving in power.

Earlier makers were reluctant to use the draw, which was not fully accepted until about 1820. No doubt their objection was the reversal of the train which subtracts energy from the balance and makes a stronger mainspring necessary. Their solution was a counterpoise to the lever to preserve the locking against change of position or sudden movement of the watch. For a very light lever the losses due to inertia of the counterpoise might be smaller than the losses due to the draw but the difference would not be significant. An examination with a microscope of counterpoised levers without draw shows the banking to be uncertain, especially when the balance amplitude is low and the momentum of the lever is insufficient to carry it to the limit of its travel. Although this will not cause the safety dart to rub the roller it will cause a variable change in the moment of engagement of the impulse pin with the fork. It is this kind of small variation in the action of an escapement that causes erratic changes of rate.

A better alternative to the angle of draw might be found in magnetic bankings. The magnetic attraction would reduce as the square of the distance of the lever from the magnet. This would give a high draw value during the supplementary arc and a rapidly diminishing value during the unlocking when draw is unnecessary. Modern watches can be made from non-magnetic materials and so the rate would not be affected by the magnets.

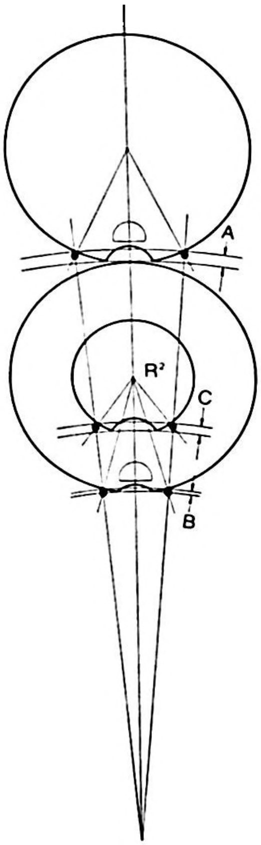
A system sometimes used by Breguet and Berthoud employs a thin spring resting on a cam fitted to the lever arbor; Fig 452 shows this arrangement in which the lever is urged to the banking pin as



452 Auxiliary draw

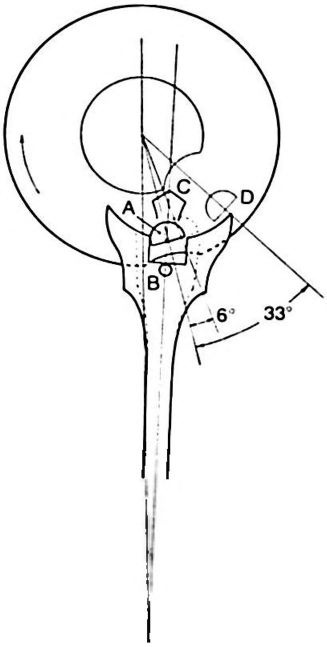
the lobe of the cam passes the peak of the spring. Although effective in holding the lever to the banking it has the defect of generating friction throughout the escaping angle with the greatest draw at the centre of the action where least is required.

The Balance Roller
The earliest lever escapements made in England in the eighteenth century, including Mudge's lever watch, employed a form of double roller on the balance axis. The upper part carried the impulse pin and the lower provided the safety action in conjunction with the guard pin or dart. With a short lever turning through a small angle this arrangement is essential to ensure low friction in the safety action. Early nineteenth-century Continental levers were longer, after the fashion of Breguet, who was at that time the leading maker of the escapement. With a long lever the arcs of intersection of the circles for the roller and lever are greater for a given lever angle, and a single roller safety action can be used. In Fig 453 the ratio of 5:1, at *A*, allows a safe intersection and a single roller is quite safe. For the ratio of 3:1, at *B*, the intersection is too shallow and the pin would jam on the edge of the roller. By using a separate, smaller roller, as at R^2, the intersection at *C* is increased and the action is safe while the friction of contact is reduced. Vertical pins are used for single rollers and horizontal pins or darts for double rollers.



453 Safety roller security:
At *A* the intersection of the safety action is secure with a 5:1 ratio
At *B* the intersection is unsafe with a 3:1 ratio
At *C* the intersection for the 3:1 ratio is secure with a smaller safety roller R^2

Fig 454 illustrates the necessary increase in the length of the lever horns that a reduction in safety-roller diameter demands. The impulse pin *A* has entered the fork of the lever and the guard pin *B* is free to pass through the crescent. If the roller is turned back through 6° the horn of the lever can contact the impulse pin to supply the



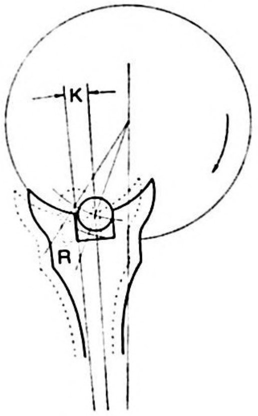
454 Effect of safety-roller diameter on the lever horns safety action. In fact it can be seen that for a single roller escapement the horns are not necessary.

For the smaller roller the crescent needs a wider angle of opening and the guard pin *C* will enter 27° before the ruby pin *D* reaches the fork. The extra angle of safety required must be added to the horn. The smaller the safety roller the longer the horns must be. Note that the clearance between the impulse pin and the horn must be greater than the clearance between the guard pin and roller to prevent the pin catching the tip of the horn.

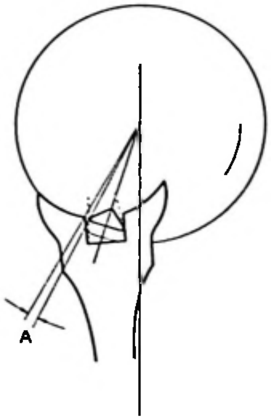
The shape of the impulse pin has an influence on the lever angle and the impulse loss due to running clearance of the pin in the lever fork. The cylindrical pin was commonly found in the nineteenth century. It is the least desirable shape and causes excessive run to the banking. Fig **455** shows at *K* the extra angle, in addition to the run to the banking, that the lever must turn in order to disengage the pin.

The triangular pin was highly favoured by the best Swiss makers in the late nineteenth century. It offers least frictional contact surface with the fork during impulse. In Fig **456** at *A* it can be seen that the running clearance is excessive at the moment of unlocking. Sometimes the clearance is reduced by narrowing the mouth of the fork as indicated by the dashed line, but the shape has insufficient merit to warrant the difficulty of forming the fork to the correct angle. The impact of the rapidly accelerating lever as it takes up the clearance combines with the small contact area to wear a depression in the notch. The difficulty of making a close-fitting hole for the pin is a further disadvantage of the shape.

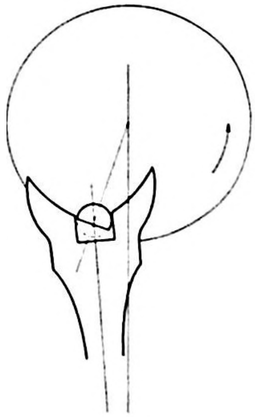
The flattened cylindrical pin shown in Fig **457** overcomes both defects to transmit the impulse without loss in running clearance and without extra run to the banking. Draw the circle for the pin at the intersection of the lines for the lever and roller angles at the moment of unlocking. Draw the lines for the sides of the fork touching the circle. At the tangent to the impulsing side of the fork draw the flat of the pin at 90° to the roller radius. Make the drawing



455 Excessive lever angle caused by cylindrical pin



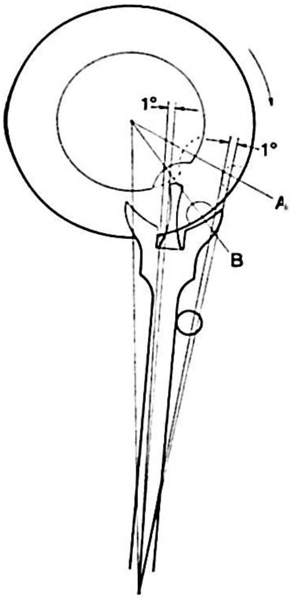
456 Excessive running clearance of triangular pin



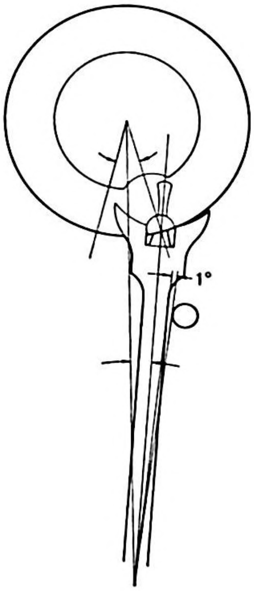
457 High efficiency semi-cylindrical pin twenty times actual size and take the dimension for the flat from the drawing.

The action of the fork and roller is shown in Figs **443a, b** and **c**. In Fig **458a**, with the roller turning in the direction of the arrow, the safety action at position *A*, in dashed lines, is supplied by the safety roller and guard pin. At position *B*, with the guard pin able to enter the crescent, the safety action is supplied by the impulse pin and lever horn. The clearance between the impulse pin and horn is due to the 1° run to the banking. It is important that this angle of clearance does not exceed the angle of locking.

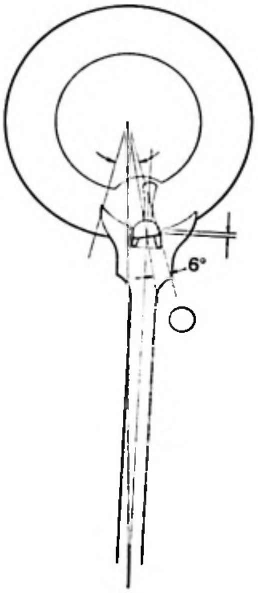
In Fig **458b**, the impulse pin has contacted the fork and lifted the lever from the banking. If the escape wheel unlocked in this position the corner of the fork would butt on the corner of the pin and cause a faulty action. A further 2° of lever movement are required to unlock and the balance will turn through 6° to reach the position shown in Fig **458c**. Here the impulse pin is safely in the fork and ready to receive the impulse. Note that the depth of engagement at the beginning of the impulse is very shallow with a 3:1 lever roller ratio. Care must be taken with the shaping and finishing of the fork and horns if the action is to be reliable and efficient.



458a Safety action supplied by lever fork

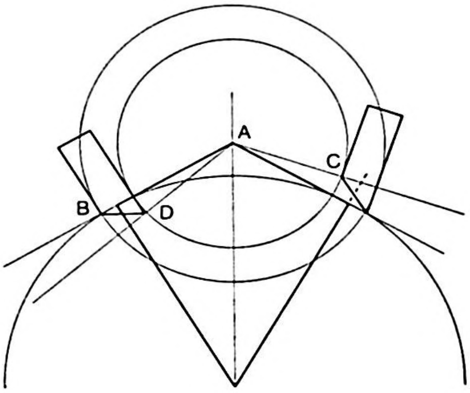


458b Lever lifted from the banking



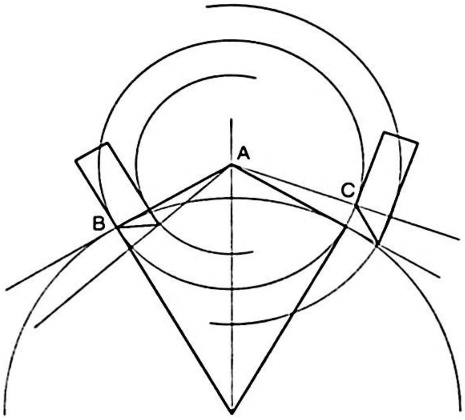
458c Completion of unlocking and start of impulse

Some high-grade escapements include the run to the banking in the 10° lever angle. For a given-size roller this has the effect of reducing the escaping angle but necessitates shortening the lever to make the fork and roller intersection more shallow. Unless the escapement is for a very large watch the reduction in escaping angle is not an advantage and the safer intersection of the 3:1 ratio is better.



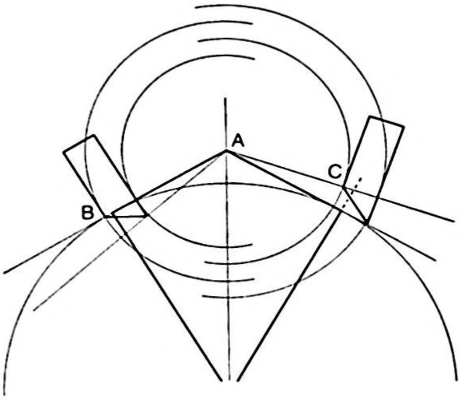
459 Equal impulse pallets

The Pallets and Escape Wheel
The increase in the draw at the entry pallet during the unlocking makes the action heavier than that of the exit pallet where the draw decreases. For this reason consideration must be given to the radii of the locking faces of the pallet. As made by Mudge the pallets gave equal impulse for unequal locking. With this arrangement, shown in Fig 459, the centres of the lifting inclines fall at equal radii from the pallet centre *A*. The locking radius *AB* is greater than *AC* by the full width of a pallet so that the resistance to unlocking is greater on the entry pallet.



460 Circular lockings

At the opposite extreme the lockings can be of equal radius with unequal impulse. This is shown in Fig 460 where the locking faces fall on a circle struck from the pallet centre so that radius *AB* equals *AC*. The impulse radius of the entry pallet is shorter than the exit by the width of a pallet. A force that would be sufficient to lift the entry pallet would be too great for the exit. If the force were adjusted to suit the exit the escapement could, at low balance amplitude, set on the entry incline.

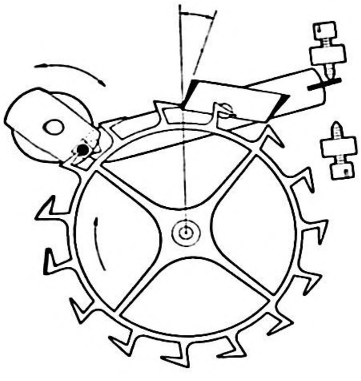


461 Semi-equidistant pallets

A compromise is illustrated in Fig **461** where the lockings and inclines are described as semi-equidistant. The radius *AB* is longer than *AC* by half the width of a pallet and the impulse radii are equal at one quarter of the lift on each pallet.

Fig **459** shows the arrangement commonly used in English ratchet-tooth escapements because the radius *AD* is greater than that in Figs **460** and **461**. This is beneficial when a heavy balance is used with a strong balance spring which needs more power to wind it through the lifting angle. The increased resistance to unlocking is easily overcome by the balance spring.

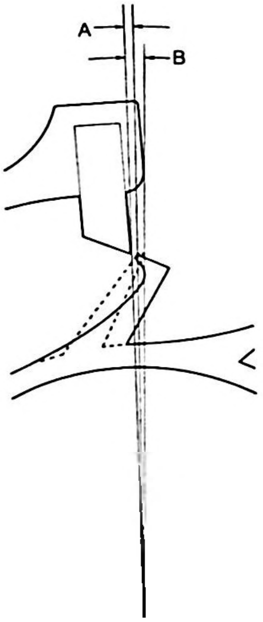
Fig **461** is best suited to the club-tooth escapement in which the lift is divided between the pallet incline and the tooth incline. Note that in each case the pallets are set out relative to the equal angles each side of the centre line.



462 Lever escapement by John Leroux

A quite different arrangement is shown in Fig **462** of an escapement by John Leroux made in 1785. It is particularly interesting because it is the first escapement after Mudge's to include improvements in principle and design. The most obvious difference is in the shape of the escape-wheel teeth and the pallets. The whole of the lift is in the incline of the teeth while the pallets serve only to lock at equal radii.

This arrangement offers equal lift and equal lock and at first sight seems to be an attractively simple solution to the inequalities of inclined pallets. This inequality interested later makers in the nineteenth century, notably J. F. Cole and S. Marait. Their solution was the rediscovery of Leroux's principles but, in an era of high-precision watches, the inability of the wheel teeth to retain oil was soon discovered to affect the rate and the escapement was abandoned. J. F. Cole made some examples with a small lift on the pallet stone in an attempt to prevent the oil being scraped from the wheel teeth, but these did not prove to be any better.



463 Drop angles for escape-wheel teeth

The modern form of tooth is a compromise between that of Mudge and that of Leroux, with the incline partly on the tooth and partly on the pallet. This is doubly beneficial, for the shape is better suited to oil retention and reduces the drop necessary for pallet clearance behind the tooth during the unlocking. Fig **463** shows at *A* the decrease in drop angle required by the club tooth. Note that the drop for the ratchet tooth is measured at *B* from the locking face of the tooth and must include the tooth thickness. The angle of incline of the club-tooth is lower than the angle of the pallet to avoid the scraping action which removed the oil from Leroux's teeth. Fig 464 shows the angle of the tooth incline as it approaches the corner of the pallet, and, in elevation, Fig 464a shows the bevelled edge of the tooth that concentrates the oil at the friction surface.

The locking face and incline of the tooth are polished. Modern wheels are made of steel but some earlier makers used brass. There does not seem to be any advantage in either material but for mass-produced wheels steel is easier to polish.

Early attempts to improve oil retention at the escape-wheel teeth included slotting the tips (Breguet and Emery, Figs 465a and b), cutting hollows into the locking faces (Emery, Fig 465c) and drilling from the back of the tooth to produce a reservoir with a small hole at the locking corner (Breguet, Fig 465d). None of these methods survives and none exhibits any particular ability to concentrate the oil at the pressure points.

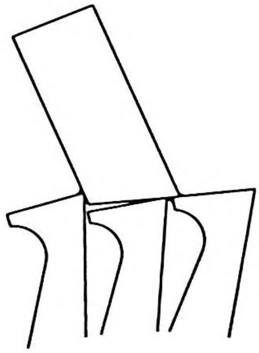
Note that the locking faces of Leroux's pallets, Fig 462, are inclined to the radial of the wheel tooth to produce a draw angle. This is the earliest known watch with draw and the credit for its introduction is undoubtedly due to Leroux. Emery, who is sometimes credited with its earliest use, most certainly did not use it in any of his known watches.

A further significant difference in Leroux's escapement is in the lift angle of the pallets. These embrace only 2 teeth of a 15-toothed wheel for an included angle of 24°. Mudge's embraces 5 teeth of a 20-toothed wheel for an included angle of 90°. The effect of this is shown in Fig 466, where pallet *A* at 90° moves through a greater distance than pallet *B* for the same 5° angle of lift. The inertia losses in *A* will be many times higher than the losses in *B* and will subtract greater energy from the escapement. The lift surface of *A* is longer than *B* and this too will absorb energy by increased friction.

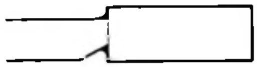
The shorter locking radius of *B* is also beneficial to the self-starting of the escapement. When wound from the run-down condition the balance will have a greater leverage over the friction and draw. If the radii are too short, as are Leroux's, the escape wheel will have insufficient power to lift the inclines and the watch will not self-start if stopped during the wound condition. For modern escapements two and a half spaces embraced by the pallets, making 60° of a 15-toothed wheel, is a good compromise between the demands of unlocking and impulse.

The locking depth also is affected by a change in radius. In Fig 466 the locking at radius *A* is safe at 2° but at radius *B* the depth is reduced and unsafe. To overcome this Leroux increased the locking angle but this is undesirable.

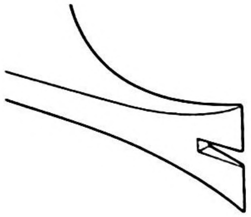
Increasing the depth of locking increases the escaping angle by the product of the increase times the lever to roller ratio. Only improved quality of construction can be accepted as the solution and it is a fact that modern escapements require greater precision of manufacture than their earlier counterparts.



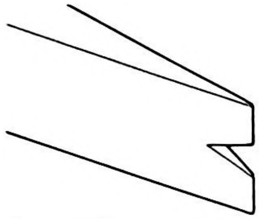
464 Correct action of lifting angles of tooth and pallet



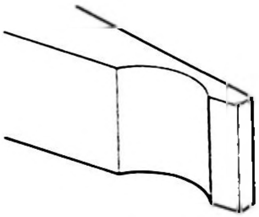
464a Oil bevel of club-tooth wheel



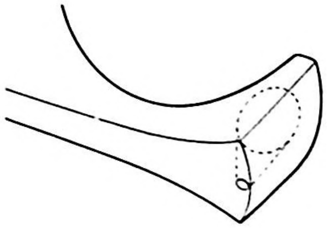
465a Breguet oil retention slots



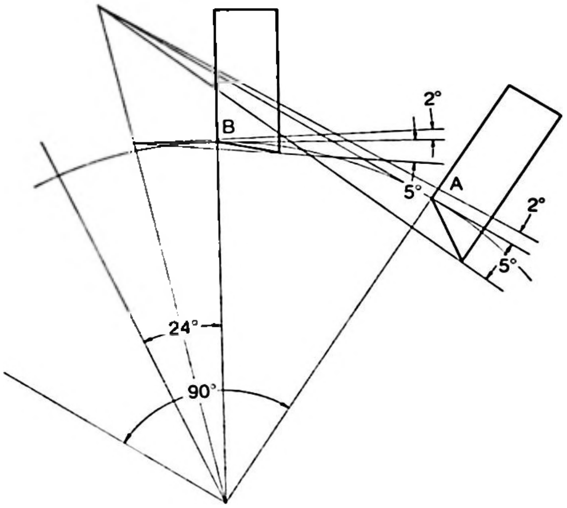
465b Emery oil retention notches



465c Emery oil retention grooves



465d Breguet oil retention cone piercings



466 Effects of change of impulse radius

The escaping angle of 30° for the modern escapement is suitable for a watch larger than 40 mm diameter. For smaller watches the angle should be increased to about 35° to 40° depending on the size of the watch. The smaller the watch the larger the escaping angle required. This is because the inertia of a balance wheel decreases rapidly as the balance is made smaller and low escaping angles have a high unlocking resistance.

Increasing the escaping angle spreads the forces of unlocking and impulse so that the action is gentler. This does mean that the balance spring must be wound through a greater angle to complete the impulse, but as small watches have very weak balance springs the escapement will not set on the impulse face as would be the case with a large watch.

The vibration period of the balance will affect the action of the escapement. Most pocket watches are designed for 18,000 vibrations per hour. If this is increased to, say, 21,600 a stronger balance spring will be needed if the inertia of the balance is not to be reduced. At low amplitudes this may result in insufficient power at the escape wheel to wind the stronger balance spring through the impulse angle, and the escapement will set. A 15 per cent increase in a 30° escaping angle (approx 5°) would restore the balance of forces.

Escapements for modern, high-precision watches have high-frequency vibration periods of 36,000 per hour. These have high escaping angles to avoid impulse losses caused by escape-wheel inertia. The increase in lever angle is confined to the lift while the lock and run to the banking remain as before. Stroboscopic photographs of the escapement in action show that the tooth is unable to catch the pallet incline for the first part of the lift angle. Although the escaping angle may be as high as 55° the lift is not much greater than 45° due to the inertia loss. The escapements require a powerful mainspring to produce a total balance arc of 280°. Lubrication problems have prompted some makers to reduce the number of vibrations to 28,800 per hour.

The ability of the escape-wheel tooth to catch the incline of the rapidly departing pallet after unlocking was a subject for conjecture among horologists for many years. It was not until 1951 that the then head of the National College of Horology in England, Major Andrew Fell, produced by means of high-speed photography a film of the action of an escapement of 18,000 vibrations per hour.

This showed beyond doubt that the tooth of the escape wheel remained in close contact with the pallet stone throughout the unlocking and impulse. It was earlier believed that the recoil of the wheel due to the draw would cause the tooth to lose contact with the pallet so that the beginning of the lift was wasted. One reason for this belief was the presence on the pallet incline, of some old English watches, of a depression caused by the impact of the escape-wheel teeth. Since the escapements of English watches usually vibrated 14,400 times per hour the depression, in the light of the film of the escapement vibrating 18,000 times, could not have been caused by impulse lag. The reason for this phenomenon lies in the slow vibration of the heavy balance which needs a strong balance spring and consequently a powerful mainspring to help to raise the supplementary arc.

As the escape-wheel tooth rounds the locking corner it accelerates rapidly along the incline to take up the running clearance of the impulse pin in the fork and the shift in position of the escapement pivots. The acceleration is halted abruptly when the thrust of the fork meets the impulse pin. The resultant pressure of the tooth, always at the same place, causes the wear on the incline.

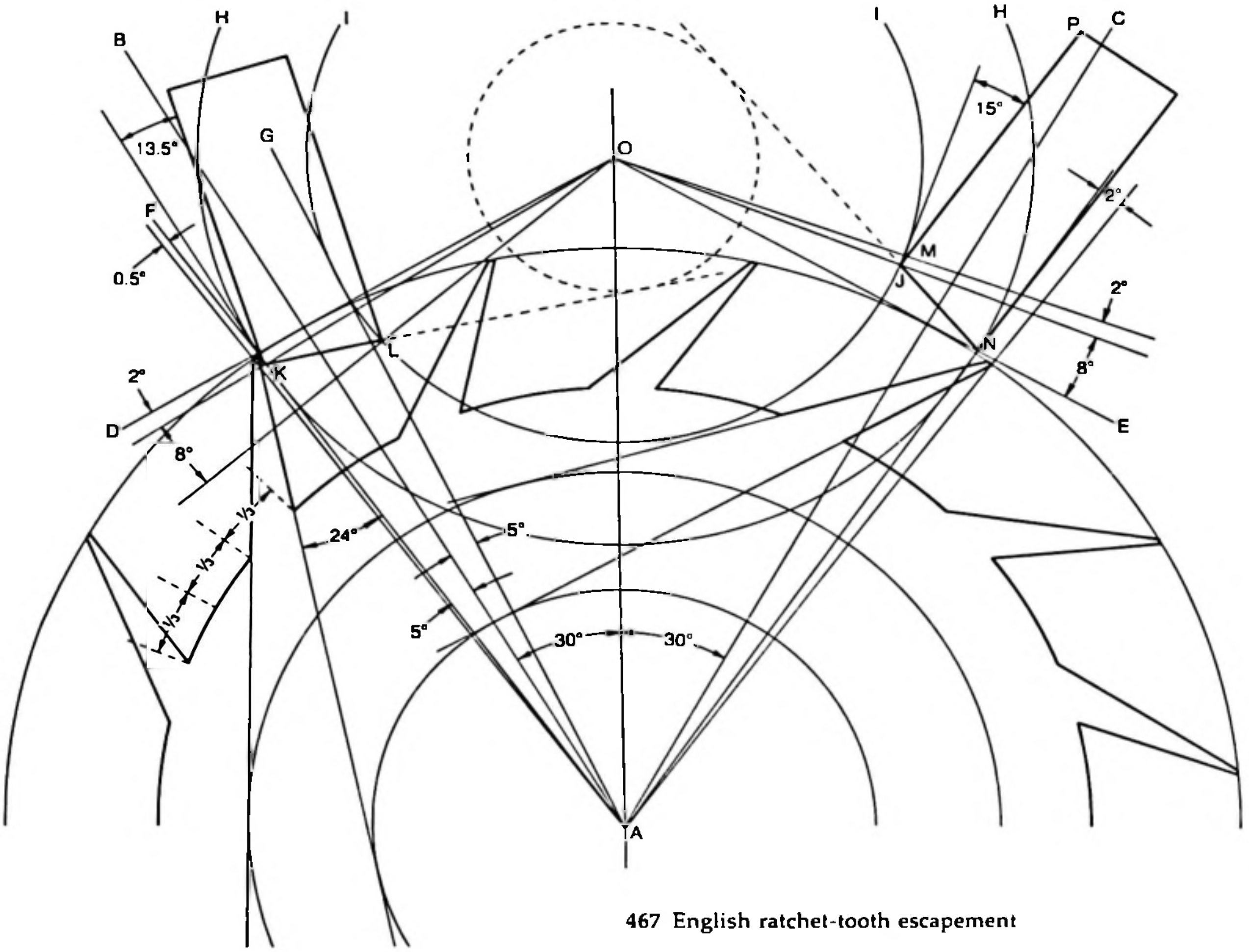
With the faster-vibrating 18,000 escapement the acceleration of the wheel tooth more nearly equals the departing velocity of the incline and the pressure of the tooth is applied more gently in the early part of the lift.

To Set Out an English Escapement with Ratchet Wheel of 15 Teeth (Fig 467)

The pallets embrace 60° of the escape wheel which is $\frac{360}{15} = 24 \times 2.5$ teeth $= 60°$. The lever angle will be 10° including 2° of locking with 8° of impulse. An extra angle of 1° will be allowed for run when planting the bankings.

Set out the lines *AB* and *AC* at 30° to the centre line of the pallets. At any convenient distance mark the centres for the wheel and pallets. At 60° to the centre line put in the tangents *OE* and *OD*. Their intersection with *AC* and *AB* is tangent to the radius of the wheel teeth. Draw the lines *FA* and *GA* at 5° each side of *BA*. This is the impulse angle of the wheel and leaves 2° of drop. From *O* strike the arcs *H* and *I* which are the paths described by the corners of the pallets.

From *O* draw in the angles *DOK* of 2° and *KOL* of 8°. Join point *K* to point *L* to form the lifting incline of the entry pallet. At the intersection of *FA* and *DO* draw a line perpendicular to *DO*. At 13.5°



467 English ratchet-tooth escapement

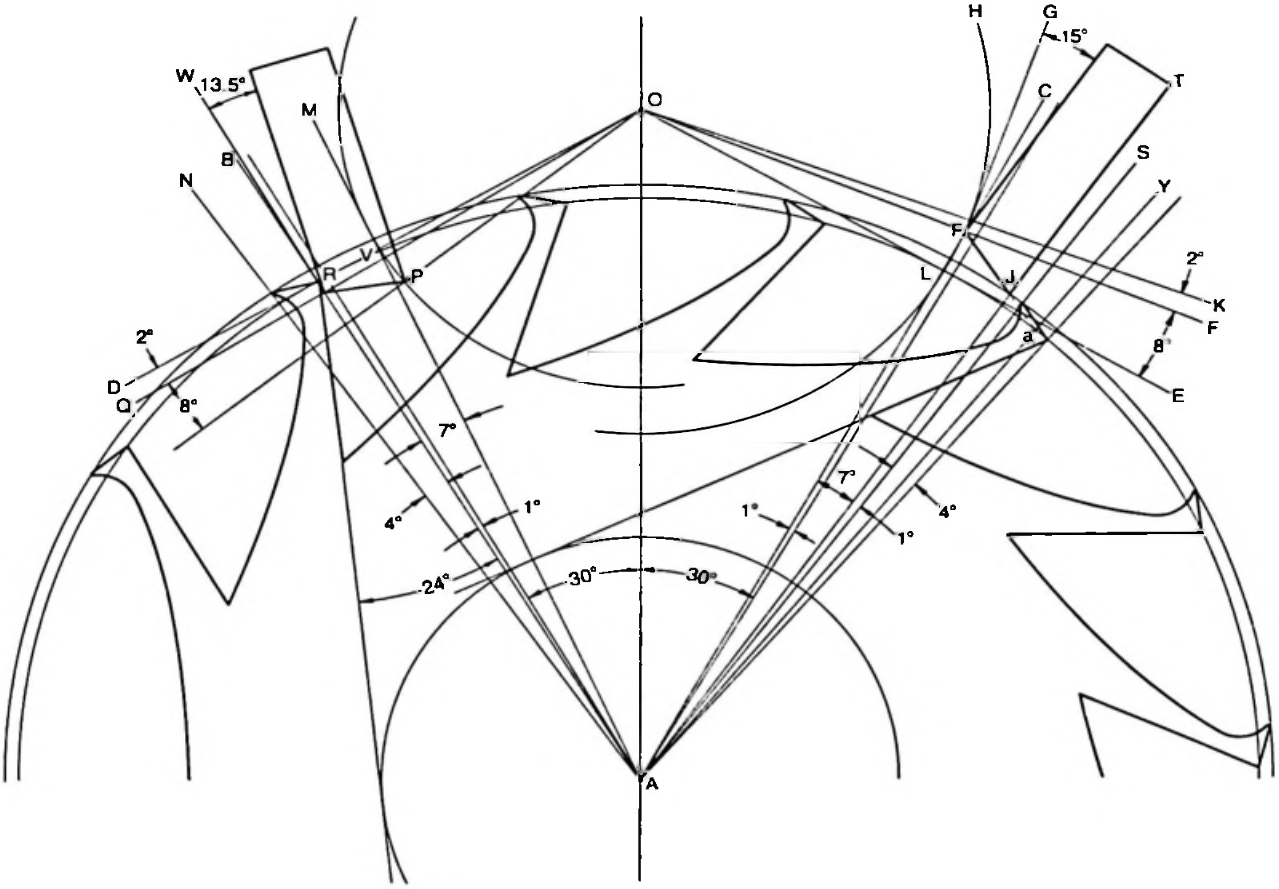
to this line draw the locking face of the pallet and extend this to point *K*. Parallel to this, and from point *L*, draw a line to complete the entry pallet. Draw in the locking and lift angles *OMJ* and *OJE* for the exit pallet outside the circle of the wheel. Join point *N* to point *J* to form the lifting incline of the exit pallet. Note that the entry and exit inclines are tangents to a common circle struck from the pallet centre.

From *M* draw a line vertical to *OM* and at 15° to this draw the angle of the locking face *MP* extended to point *J*. A line parallel to this from point *N* will complete the exit pallet.

The diameter of the circle for the roots of the teeth is approximately three-quarters of the total diameter of the wheel. The width of the tooth tip is 0.5°. The locking face is 24° from the radial and the width of the root approximately a third of the pitch.

To Set Out a Semi-Equidistant Club-Toothed Escapement with Wheel of 15 Teeth (Fig 468)

Set out the angles of 30° to the centre line as for the English escapement and pitch the centres *A* to *O* of wheel and pallets at a



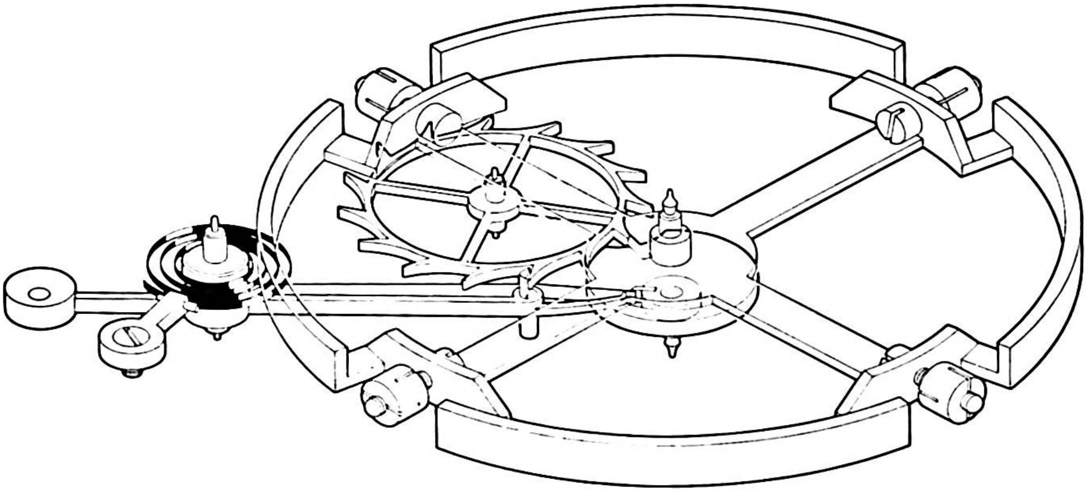
468 Semi-equidistant club-tooth escapement

convenient distance. Draw the locking tangents *OD* and *OE* of 60°.

Of the 12° half-tooth space 7° is allowed for the pallet width and 4° for the tooth width leaving 1° drop. At an angle of 1° anticlockwise of the direction of rotation of the wheel, draw *AB* and *AC*. The radius of their intersection with *OD* and *OE* is the radius of the locking corners of the teeth as represented by the arc struck from the wheel centre *A*.

Mark off the angle *CAT* at 7° for the pallet width and *TAY*of 4° for the tooth width. Mark off the angle *EOF* of 8° for the lift and *FOK* of 2° for the locking. Scribe the arc *OH* of the locking corner of the pallet from the locking point *L*. Where arc *HL* crosses *OK* draw a line *FG* perpendicular to *OK*. At 15° to this, draw the locking face of the pallet extended to *F*. Draw a line from point *F* to complete the incline of the pallet. This line, if extended, would pass through point *a* at the locking radius of the wheel. Point *J* is now the full radius of the wheel and the arc can be drawn. Draw a line from *J* parallel to the locking face to complete the pallet.

Draw the drop angle *TAS* at 1° to *AT* and complete the lift of the tooth of 4° at *aS*. Draw the angles *MAB* of 7° for the entry pallet and



469 Pivoted detent escapement

BAN of 4° for the tooth. From point *V* draw the arc of the path of the locking corner of the pallet and the angle *OVP* including the 2° of locking *QOD*. From point *R* raise the line *RW* vertical to *OD* and at 13.5° to this draw in the locking face of the pallet extended to *Q*. Join *P* to *Q* to form the incline of the pallet and a line from *P* parallel to the locking face to complete the pallet. Join *N* to *R* to form the incline of the tooth. The locking face of the tooth is at 24° to the radial. The radius of the tooth root is between a quarter and a third of the wheel diameter.

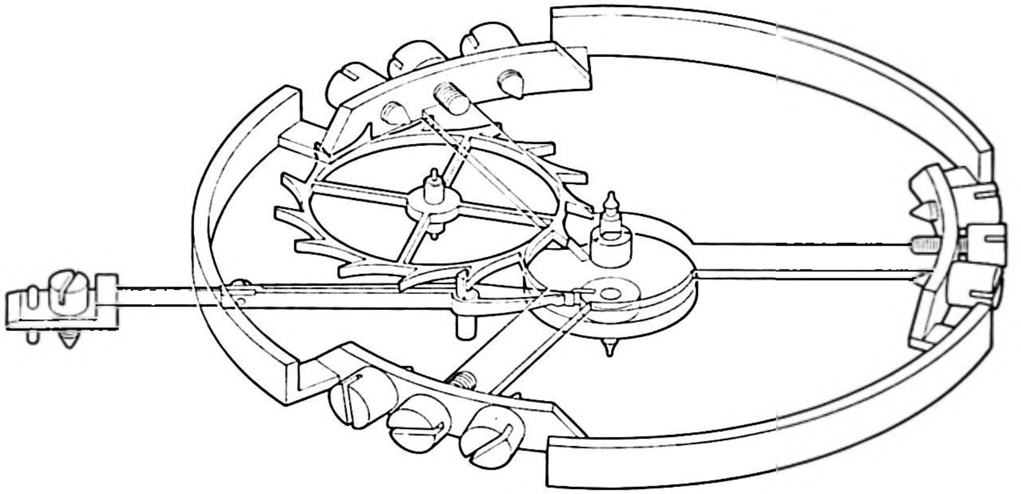
It is not necessary for the pallet and tooth widths to be set at the angles given. The proportion of tooth to pallet can be varied to suit the convenience of the construction. It is important that the incline of the tooth is never, during the lift, coincident with the pallet incline. If the tooth incline is designed as a continuation of the exit pallet lift, as described, the action will be correct.

Chronometer

The chronometer, or detent escapement, is a detached, single impulse escapement in which the impulse is delivered directly by the escape wheel to a roller on the balance axis. After impulse the escape wheel is locked on an intermediate component to leave the balance free during the supplementary arc. It is illustrated in Fig **469** with pivoted detent and in Fig **470** with spring detent.

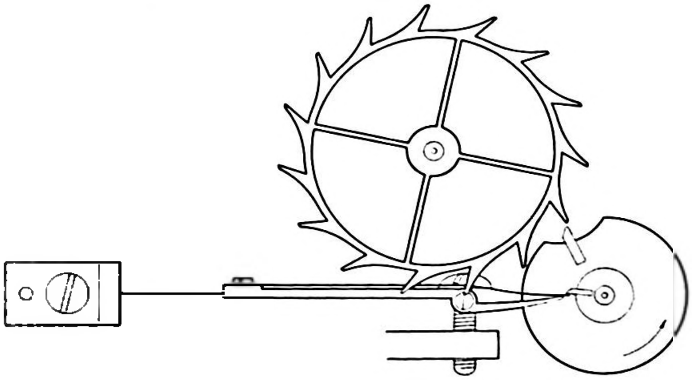
John Arnold was the first maker of practical, pivoted detent escapements which he used in watches made in the eighteenth century. The spring detent escapement was invented simultaneously by John Arnold and Thomas Earnshaw in 1782. The modern form of escapement is similar to Earnshaw's design. Early escapements had escaping angles of about 52° depending on the ratio of escape-wheel diameter to impulse-roller diameter. Nineteenth-century makers reduced this to 36° for watches and 45° for marine chronometers.

The action of the escapement is simple and the impulse is given

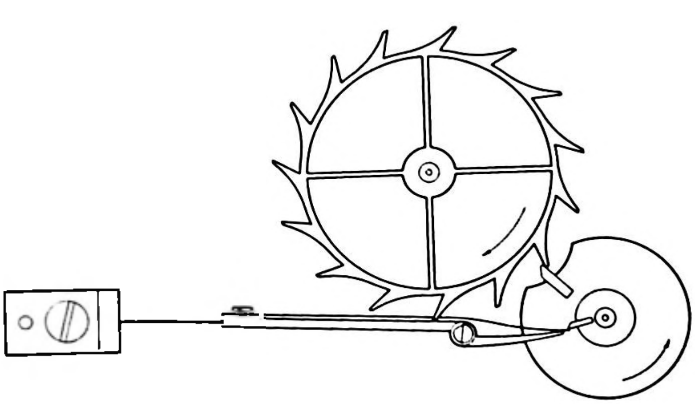


470 Spring detent escapement

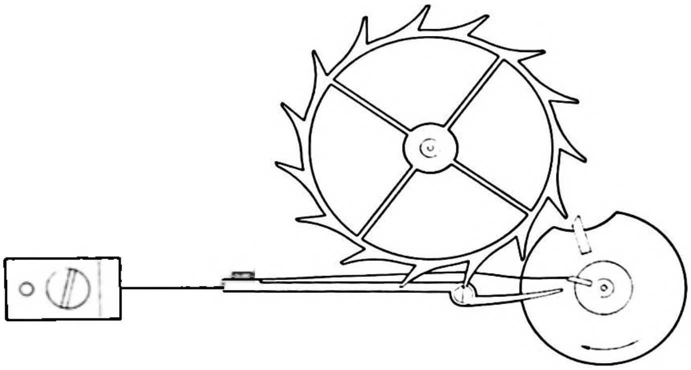
virtually without friction so that the escape-wheel teeth do not require oiling. In Fig **471a**, the balance roller is turning anticlockwise and the unlocking stone is in contact with the passing spring. In Fig **471b**, the stone has lifted the detent aside to release the tooth of the escape wheel from the locking stone. A tooth of the wheel has dropped on to the impulse roller pallet to impulse the balance.



471a Escape wheel locked with unlocking stone in contact with the passing spring



471b Escape wheel unlocked and impulsing balance roller



471c Passing spring flexed aside during return vibration of balance

During the impulse the unlocking stone will pass out of intersection with the passing spring and the detent will fall back to the banking ready to receive the following tooth of the escape wheel. After the impulse is completed the balance will complete the supplementary arc without disturbance. The return vibration is completed without an impulse while the unlocking stone flexes aside the passing spring leaving the locking undisturbed, as in Fig 471c.

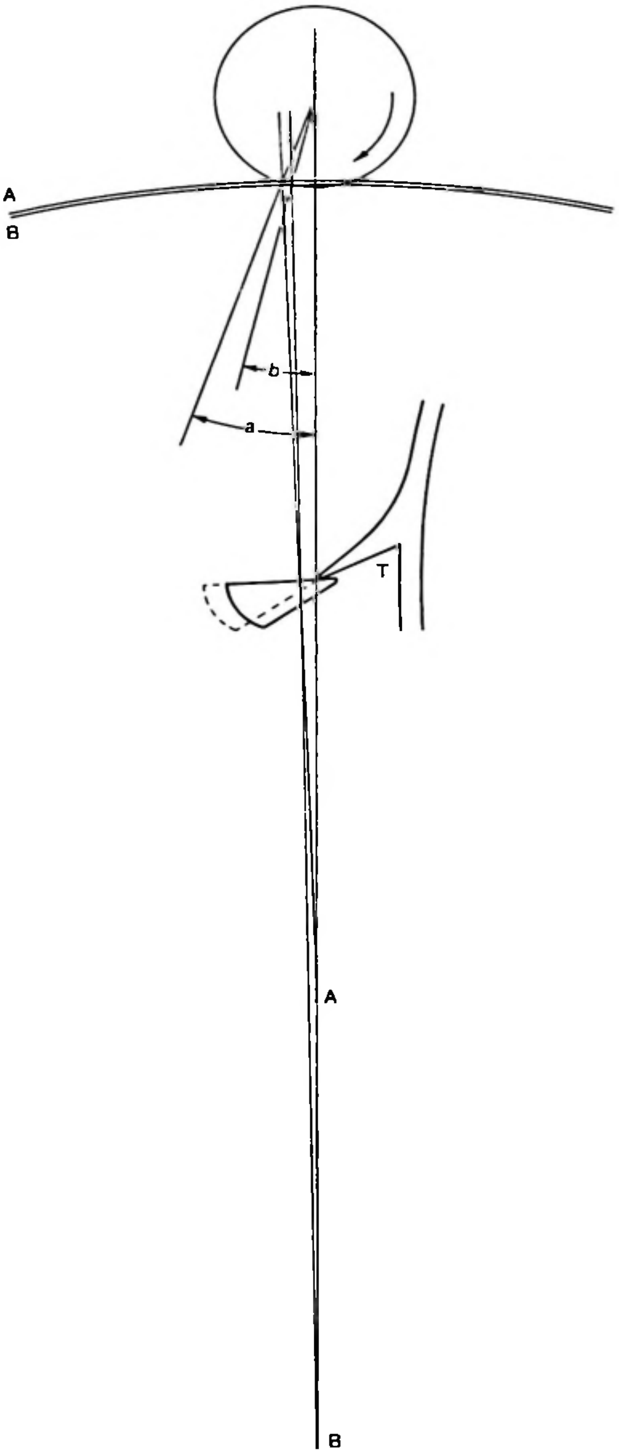
The quiescent point of the balance spring is on a line passing through the centre of intersection of the unlocking roller and the passing spring tip. This ensures that the unlocking angle is equally distributed about the centre line to reduce the risk of setting if the supplementary arc is accidentally reduced. The impulse is given after the centre line and the escapement has a losing error.

The Unlocking Angle

The unlocking angle is dependent upon the acting radius of the unlocking stone, the depth of intersection with the passing spring and the radius of flexing of the detent. A long detent may have a shallower intersection than a short detent so that the unlocking is completed earlier to bring the impulse nearer the centre line. On the other hand a long detent is heavier and would need a stronger spring to return it to the banking. The decrease in unlocking angle as the detent is lengthened is shown in Fig 472 where the roller for detent *A* turns through angle *a* to unlock tooth *T* and through angle *b* for the longer detent *B*.

Note that the intersection of detent *B* with the path of the tip of the unlocking stone is very shallow. Although this reduces the unlocking angle it is not wholly advantageous. The percentage change in intersection with change of position of the watch will be greater than that for detent *A* and will affect the positional rates by changing the unlocking angle. This could be prevented only by very close fitting balance pivots which would cause change of rate with change of oil viscosity.

Increasing the radius of the unlocking stone will have the same effect as an increase in the length of the detent. Decreasing the radius will allow a deeper intersection with the passing spring but will increase the escaping angle. As a general rule the radius is



472 Effects of change in the length of the detent

usually given as half the radius of the impulse pallet. This rule works well enough and gives a safe depth of intersection while ensuring the discharge of the detent in ample time to catch the wheel tooth after completion of the impulse. It is a mistake to confine the unlocking angle of the detent to the minimum necessary to unlock the wheel. The angle will be between 1° and 1.5°, and the intersection should be sufficient to double this angle. An unlocking radius of half the impulse radius will allow the detent to return safely to the banking before the impulse is completed and with acceptably small variation due to pivot running clearances.

Detent *A*, shown in Fig **472**, would be less affected by running clearances but the increased angle of unlocking will subtract greater energy from the balance. The qualities of long and short detents must be compromised to find the most suitable length. An examination of good-quality late nineteenth-century English pocket chronometers will show the average length of the detent from the tip to the flexing point of the spring to be 1.25 times the diameter of the escape wheel.

The Angle of Draw

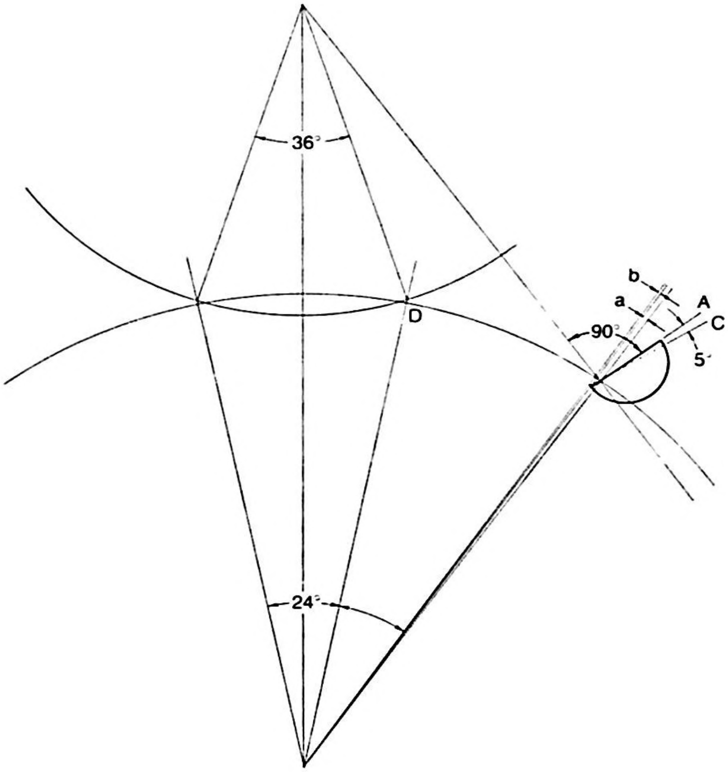
With an escaping angle of 36° and a 15-toothed wheel the locking point of the detent will not be a tangent to the radial tip of the wheel tooth. In Fig **473** the line *A*, an extension of the face of the locking stone, is at 90° to the detent at the point of intersection with the circle of the tips of the wheel teeth. As the stone is withdrawn to unlock, the wheel will be recoiled through angle *a* which will have the effect of drawing the detent back to the banking. But at the moment of banking there will be no draw because the pressure of the escape-wheel tooth is vertical to the face of the stone. Turning line *A* to position C will give a draw angle to the locking face but the wheel will recoil through the additional angle *b*. This causes a high unlocking resistance but ensures firm banking at the moment of locking.

Note that the locking stone cannot be turned in its drilling for this would alter the locking position of the wheel and cause the teeth to touch the impulse roller at *D*. If the impulse roller were reduced in diameter to recover the clearance then the impulse angle would be reduced. The draw angle of 5° must be allowed for when designing the detent.

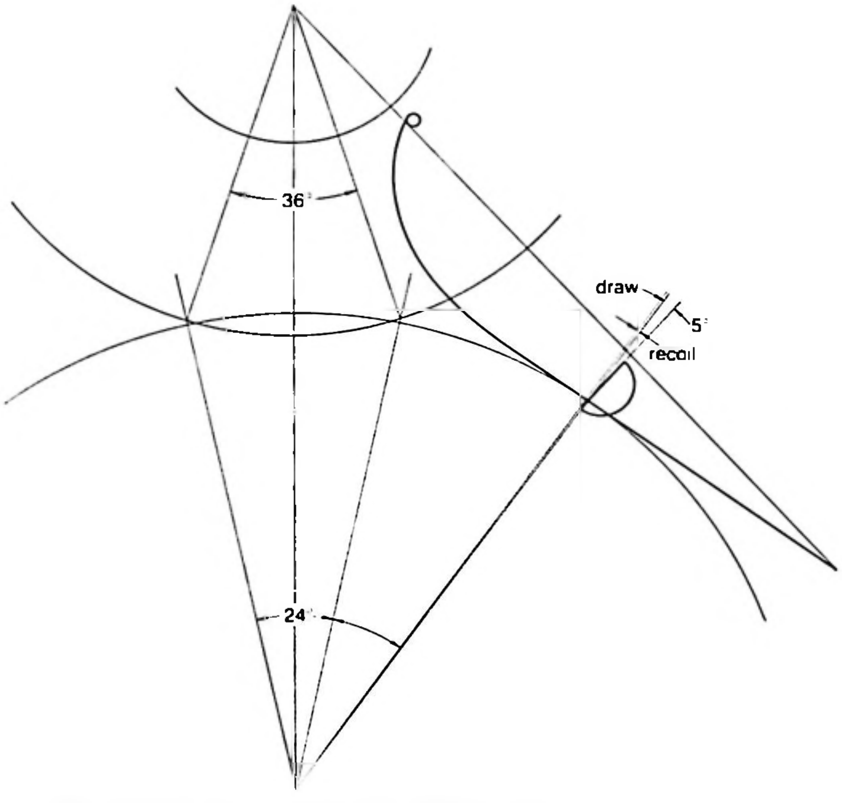
The arrangement shown in Fig **474** is after Breguet and secures tangential locking and reduced recoil by offsetting the horn of the detent to preserve the radial action of the passing spring. The spring passes under the horn and banks on a pin. This arrangement needs more height for the detent to allow the spring to pass beneath, and the horn is heavier. Although the plan has a certain attraction for the purist the extra room required, combined with the weight of the horn and the extra difficulty of manufacture, did not commend it to the English watchmaker.

The Locking Stone

The shape of the locking stone is usually semicircular. Often it passes through the detent and acts as the banking. The locking face is shortened by the draw angle and needs undercutting to clear the tip of the wheel tooth. This is especially necessary in the English escapement where the locking is not tangential. The path of the

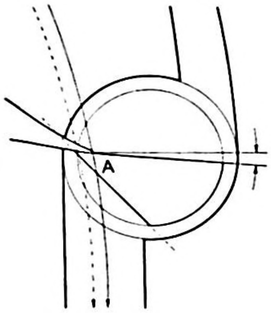

b
a
A
C
90°
5°
36°
D
24°

473 Angle of draw of non-tangential locking stone


36°
draw
5°
recoil
24°

474 Angle of draw of tangential locking stone

wheel teeth intersecting the curve of the locking stone is shown in Fig 475. The flat at *A* gives the necessary freedom for the departing tooth.



475 Locking-stone clearance for passing tooth

Pivoted Detent

Pivoted detents were not generally made in England but were very fashionable in Switzerland in the second half of the nineteenth century. The English objected to the need for oil at the detent pivots and believed the rate would be affected by its deterioration. This was undoubtedly true in the eighteenth century when Arnold made his pivoted detent watches but by the late nineteenth century oils were much improved and the objection was no longer valid.

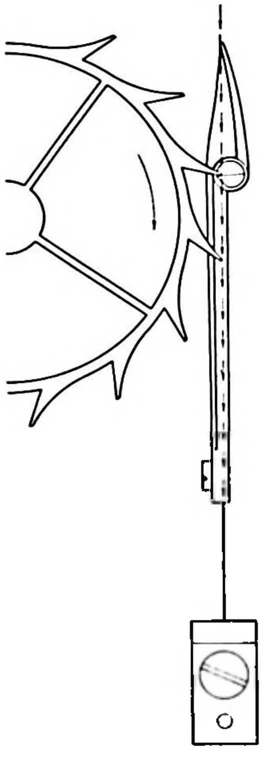
In fact the English made spring detents because they had been brought up to make them and the Swiss made pivoted detents for the same reason. There is no advantage in either type in so far as the performance of the watch is concerned. In the matter of construction the pivoted detent requires careful pitching of the pivot holes without adjustment for error. The spring detent can be made adjustable within the small limits of error of pitching.

The spring foot is the most delicate part of the English detent. The pivoted detent, with its separate return spring, is undoubtedly more robust. This leads to greater rigidity in the detent during banking and locking, and it is a fact that an incorrectly made pivoted detent will perform more reliably than an incorrectly made spring detent. The spring detent is more demanding in skill of manufacture than the pivoted detent, although it was dismissed by Ferdinand Berthoud as a cheap variety of the pivoted detent.

The pivoted detent as made by the Swiss was counterpoised presumably to avoid errors of rate with change of position in the watch; if there is any advantage in this it cannot be gained from the spring detent. Comparable rates of spring and pivoted detent watches reveal no sensible advantage for the counterpoise but the increased inertia can only be a disadvantage.

Locking Stability

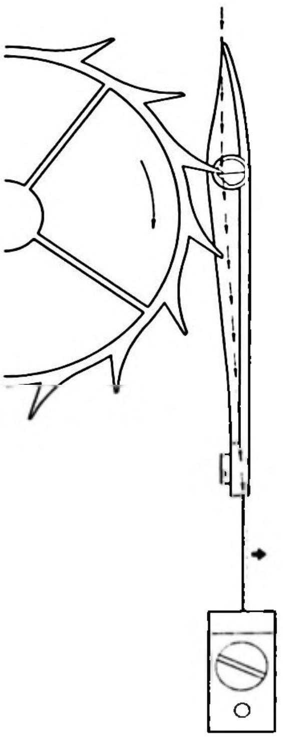
Fig 476 shows the correct path of locking pressure through the spring of the English detent. This condition is equally applicable to the pivoted detent. The effect of an incorrect pressure path is shown in Fig 477; it causes the spring to bow sideways in the direction of the arrow. The same effect is not produced with the pivoted detent where the locking force is radial to the rigid pivot, as in Fig 478. The effect shown in Fig 477 is repeated during unlocking when the inertia of the wheel during recoil causes the spring to bow and affect the stability of the unlocking angle. The inferiority of the long-term stability of rate is equally apparent with a twisted or buckled spring and the only true remedy is a new detent.



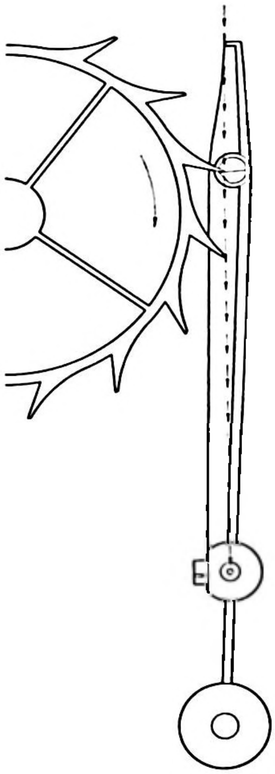
476 Correct pressure path for spring detent

The Impulse Angle

The escaping angle of 36°, shown in Fig 479, includes running clearance between the tips of the wheel teeth and the roller plus the necessary drop to ensure safe intersection of the tooth with the



477 Effect of incorrect pressure path for spring detent

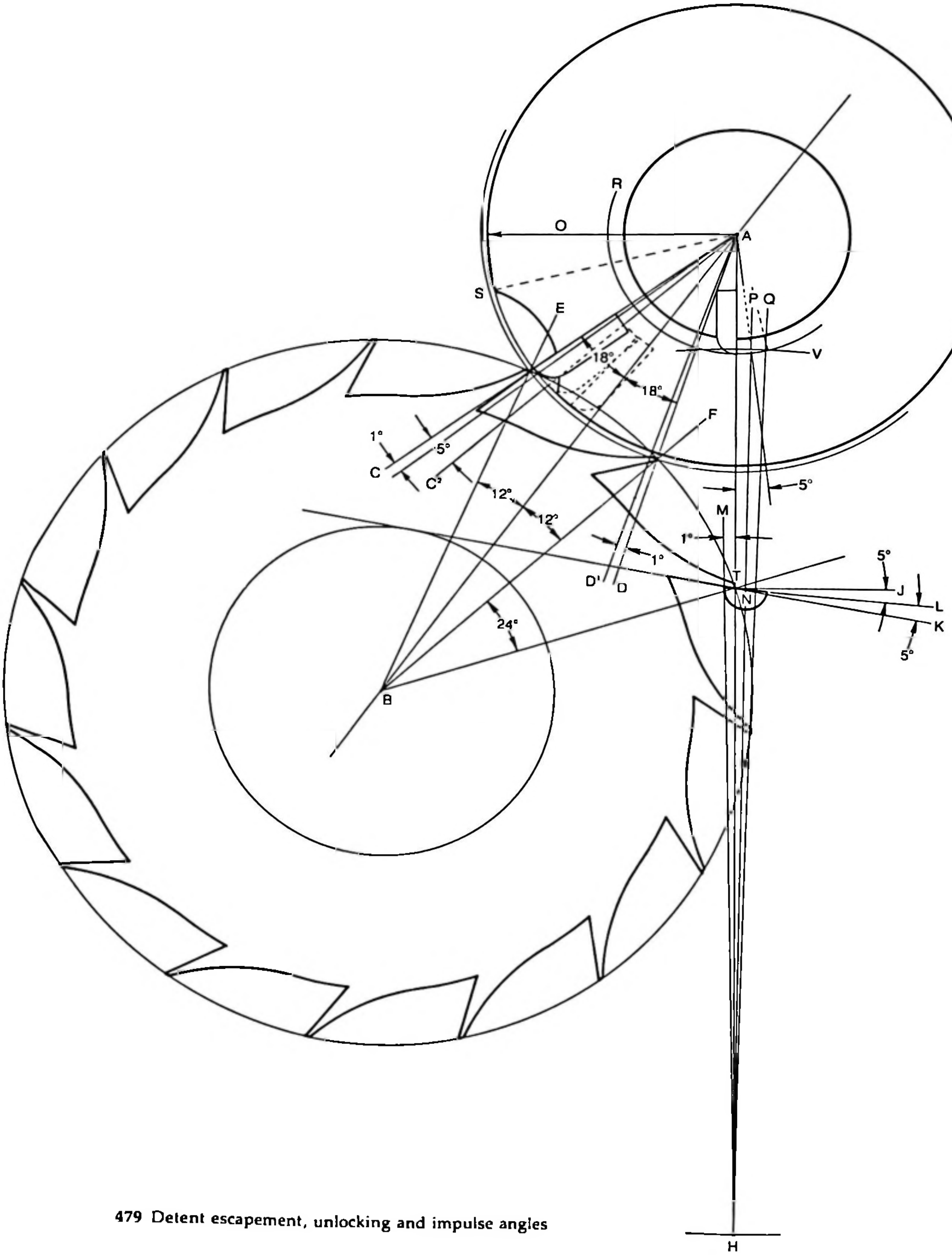


478 Pressure path of pivoted detent

impulse pallet. The angle of impulse will depend upon the quality of construction of the escapement. Absolute concentricity of the wheel and roller are necessary if useless drop of the wheel tooth is to be avoided. The drop of the wheel on to the pallet cannot be avoided but must be kept to the minimum. If closely made the loss due to combined drop and freedom will be 6° of balance arc, leaving 30° of impulse. At high amplitudes, with increased mainspring power, the escape wheel will accelerate to reduce the drop and the impulse angle will increase. The escapement can be adjusted to run without the drop on to the pallet and this will increase the extent of the mid-power vibrations. But at high-power amplitudes, without drop, there is danger of the pallet butting the tips of the teeth and causing erratic action.

The inertia of the escape wheel has considerable influence on the useful angle of impulse. Practical experiments show that reducing the effective mass by about 30 per cent will raise the amplitude of balance vibration from 180° to 210°, equivalent to a 10 per cent increase in mainspring thickness for a pocket watch. These figures are for one particular watch and will vary according to the design of the escapement. But it is plain that impulse lag and the drop arising from it must be kept to a minimum if the escapement is to have a lively and efficient action.

It is usual to reduce the weight of the escape wheel by turning the rim and spokes thin and leaving the teeth only at the full width. The


O
A
R
S
E
P
Q
V
18°
18°
F
1°
5°
C
C'
12°
12°
5°
M
1°
1°
D'
D
T
N
5°
J
L
K
5°
24°
B
H

479 Detent escapement, unlocking and impulse angles

wheels are usually made from brass but some English watches have steel wheels. Many high-grade Swiss wheels are made of gold but this makes the wheel unnecessarily heavy.

To Set Out the Chronometer Escapement
(Fig 479)

To set out the escapement mark off the centres of the wheel and balance at any convenient distance. From balance centre *A* mark off the angles *CAB* and *BAD* of 18°. From wheel centre *B* mark off the angles *EBA* and *FBA* of 12°. At the radius of intersection of the angles draw the circle for the impulse roller and wheel and at 24° to *FB* the point of the locking tooth *T*. Draw the line for the detent *AH* from centre *A* passing through point *T*. Draw the circle *R* for the path of the unlocking pallet at half the diameter of the circle for the path of the impulse pallet. From the intersection of circle *R* and line *AH* mark the point of flexure *H* of the detent at one and a quarter times the escape-wheel diameter. From *T* draw line *TJ* perpendicular to the detent *AH*.

At 10° to *J* draw *TK* which is the angle of the locking face of the tooth. At 5° to *JT* draw *LT* which is the angle of the locking face of the locking stone. At 1° to *AH*, inside the circumference of the wheel, draw *HM* to define the limit of locking of the stone. At point *N* on the line *LT*, draw the semicircle of the locking stone tangent to *MH*. Point *N* is determined by the diameter of the locking stone which may be approximately one-eighteenth of the diameter of the wheel. For example, for a 9 mm wheel a stone of 0.5 mm wide would ensure adequate strength. From centre *A* draw AD^1 and where this cuts the circle for the wheel draw the circle radius *AO* to indicate the radius of the impulse pallet. At 5° to *AC* draw AC^2 which is the face of the pallet at the moment of unlocking.

The face of the unlocking pallet falls on *AH*. At 1° to *AH* draw line *PH*. The angle *AHP* is the unlocking angle. At 1° to *PH* draw line *QH*. Angle *AHQ* is the discharge angle of the detent. The intersection of arc *HV* with the circle for the path of the unlocking stone is the intersection of the passing spring and stone. The angle of the locking face of the teeth is already set by *KN*. Draw in the outline of the teeth to the desired shape. The passing crescent in the safety roller needs to be sufficiently large behind the pallet to allow for impulse lag in the wheel but angle *SAC* must not exceed the distance between two teeth.

Note that the position of the impulse and unlocking pallets is drawn to show their respective depths of intersection. With the impulse pallet at the drop point, as shown, the unlocking pallet will be at angle radius *AP*.

The Further Development of the Escapement

Of the escapements so far described the most successful is the lever escapement which has been in use, to a greater or lesser extent, since Emery began to construct his series of lever watches in 1782. It combines robustness with a high degree of detachment so that, in daily use, it can be a close timekeeper.

The best static rates of the modern lever escapement are equal to the best rates of the finest nineteenth-century chronometers. The improvements in proportion and weight reduction have produced improved balance amplitude for reduced power and greater reliability in action. A good lever watch can now keep as close a rate on the wrist as a nineteenth-century lever watch could maintain in the pocket. There can be no doubt that the limits of efficiency that can be achieved in the action of the escapement have been reached. Small daily variations that now occur when in use are due to variable forces imposed on the escapement by the agitation that the watch is subjected to by the action of the wearer.

The introduction of quick trains which have now found their optimum at 28,800 vibrations per hour have helped reduce daily variations to the present minimum. A good, modern wrist-watch will run to within three seconds per day in average use and can be adjusted to suit the wearer to average the error into only a few seconds per week.

Quick trains were first introduced by Swiss makers for mass-produced watches with a vibration period of one tenth of a second, that is 36,000 vibrations per hour. Unlike the earlier English chronographs with the same vibration period, the watches incorporated escapements especially designed to run at high frequency. In the short term the watches demonstrated a useful improvement in stability of daily rate. In the longer term the rates began to deteriorate as a result of the increased pressure and rubbing speed at the lifting surfaces of the escape-wheel teeth and the pallets. The quick-train watches had emphasized the dependence of the lever escapement upon a reserve of oil at the sliding surfaces. The solution in the short term has been to lower the number of vibrations to 28,800 to give a period of one-eighth of a second. It would be better to reduce the friction at the lifting surfaces.

Some makers have experimented with plastic components which do not need oiling. These work well enough if a close rate is not required but my own experiments, made many years ago, showed that the friction is variable with the humidity of the atmosphere and can cause wide variations in rate. If the components are not kept quite clean and free of dusty conditions the rubbing surfaces can become impacted with dirt which will cause cutting and wear. Such components cannot, in my opinion, make any long-term contribution to the lever escapement.

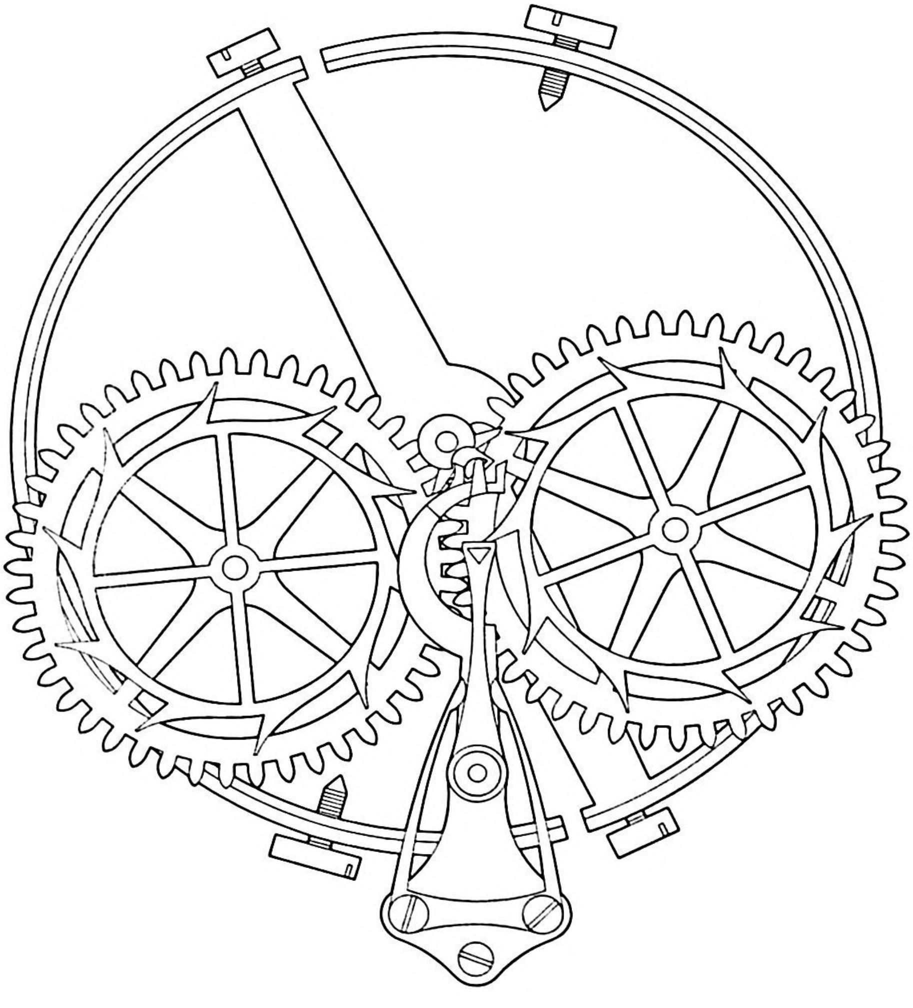
Because the lever escapement is so reliable and robust it has dominated the minds of watchmakers for 200 years. Its success lies in the impulse at each vibration with detached supplementary arc combined with its solidity of construction. These combine to allow hard usage and repeated dismantling and reassembly without the necessity for adjustment and consequent change in performance after servicing.

To supplant it a new escapement must possess the same merits with the additional advantage of the elimination of oil at the impulse teeth.

Echappement Naturel

The first practical watch escapement to employ these characteristics was Breguet's *échappement naturel,* so called because the impulses are delivered directly to the balance axis by the escape-wheel teeth so that oil is not required. It is shown in Fig 480 with two escape wheels geared together. One is driven by the train and, in turn, drives the second. Both wheels advance by a half-tooth space during each alternate impulse to the balance axis. The wheels are released for impulse from the single locking stone by a fork and roller action similar to that of the lever. It proved to be inferior to his best lever escapements and produced daily variations of up to four seconds per day when in use.

The idea of alternate impulsing directly to the balance axis with contra-rotating wheels is seductive. But in Breguet's escapement the extra friction of the pivots of the driven wheel and the back-lash in the teeth of the coupling wheels causes instability in the action. He abandoned it after 1810 and continued with his excellent lever escapements.

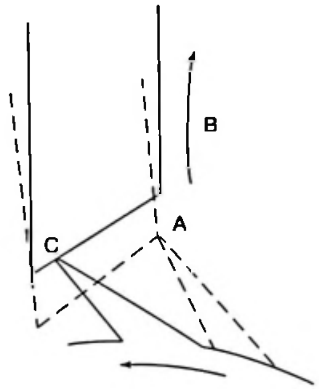


480 *Echappement naturel* escapement by Breguet

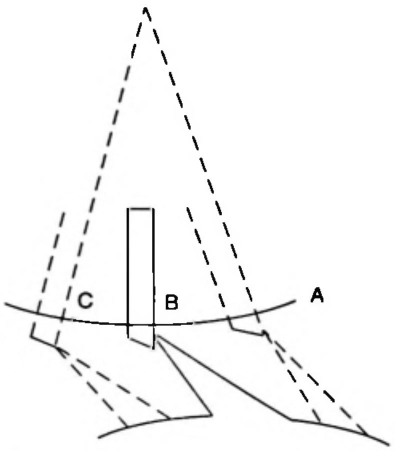
Detached Escapements Without Lubricant

If the increase in oscillator vibrations was beneficial in the short term, it did nothing for the long-term performance of the lever escapement. The modern watch, if it is to keep a close rate, needs servicing at fixed, short intervals just as did earlier examples. The principal reason is the necessity for lubrication of the long sliding impulse.

The impulses generated by a tooth sliding along the pallet incline are quite different in nature from the impulse of the detent escapement, in which sliding contact is minimal. As a consequence, the impulse does not require lubrication, while the lever impulse will not function without it. But the great merit of the lever escapement is the impulse given to the balance at each vibration.



481a Sliding impulse to lever pallet



481b Radial impulse to balance pallet

The action of the lever escapement is seen in Fig 481a. Impulse starts at *A* (seen in dotted lines). The wheel tooth impels the pallet in the direction of *B* as it slides along the inclined surface of the pallet C. The length of the surface C is equal to half the space between the two escape-wheel teeth, less only the drop of about 2°. For a watch of some 30 mm diameter with an escape wheel of 5 mm diameter there will be some 14 mm of sliding friction at each revolution of the wheel. Such an excess of friction must have lubrication if the escapement is to function. As a consequence of changes in the viscosity of the lubricant caused by ageing and climatic changes, the rate of the escapement will become unstable.

For modern, fast-beat escapements, grease is sometimes used instead of oil. But this is also affected by climate and, especially after a period of use, by change of humidity acting upon the impulse surface, partially wiped clean by the passage of the escape-wheel teeth.

The action of the tooth of the detent escapement's escape wheel during impulse is seen in Fig **481b**. The tooth will fall onto the impulse pallet at position *A* to impel the pallet to position *B*. During this action the tooth will slide radially along the pallet in the direction of the arrow *A*. From the centre line *B* of the action the tooth will recede back to the tip of the pallet at C to complete the impulse and fall away to lock the wheel.

In a small detent watch of some 30 mm diameter, the sliding contact of tooth and pallet during impulse will amount to no more than a few hundredths of a millimetre or less than 1 mm per revolution of the escape wheel. This, combined with the beneficial reversing of the sliding contact, accounts for the absence of wear after many millions of impulses, often without a jewelled pallet. As a consequence, the escape wheel teeth do not need lubrication, so that a significant variable factor is eliminated to produce a stable rate of timekeeping.

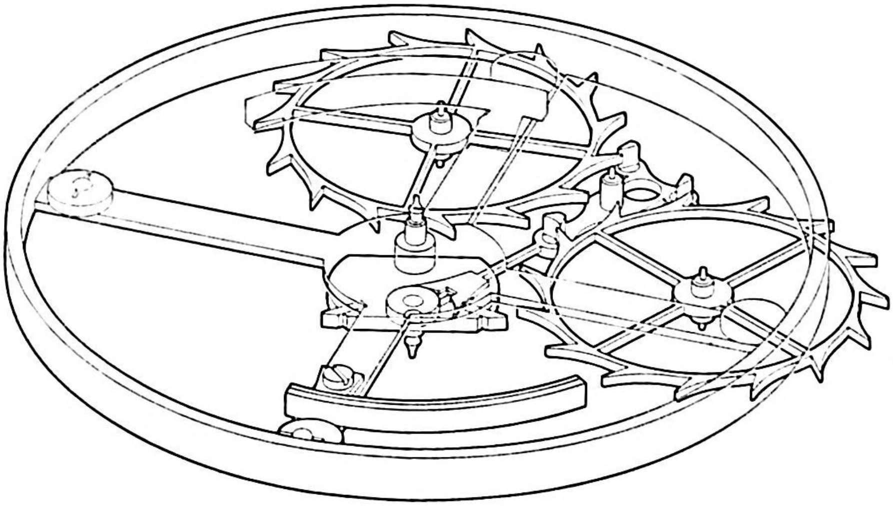
Independent Double-Wheel Escapement

As a first step to producing an escapement to give impulse at each vibration, as with the lever escapement, but employing the natural lift of the radial impulse, the escapement seen in Fig **482** was constructed. This is founded on Breguet's *échappement naturel*, Fig **480**.

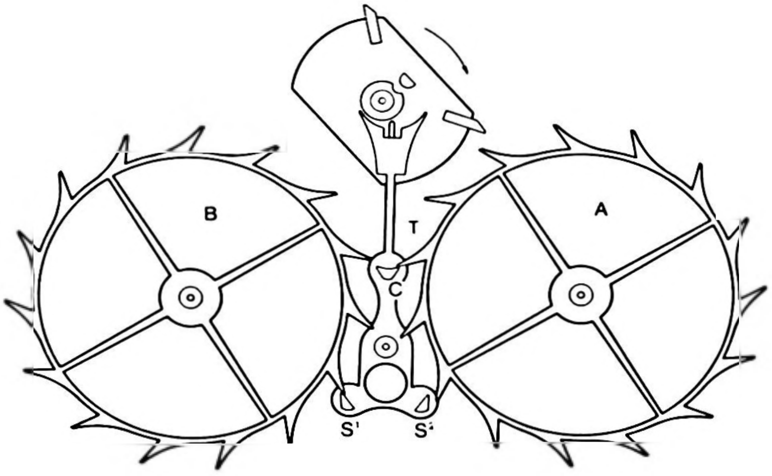
In this mechanism the two escape wheels are separately driven by individual trains, each with its own mainspring. The arrangement is seen in Fig **482** in which the balance carries a roller with two impulse pallets and a pin to engage the fork of the locking lever.

The escape wheels are released alternately to impulse the balance and then lock on the secondary locking stone ready for the following impulse.

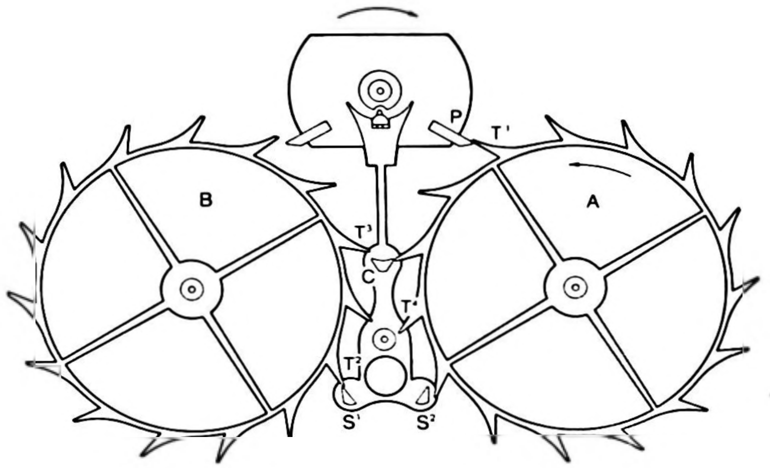
In Fig **482a** the balance roller is turning clockwise to release tooth *T* from the principal locking stone *C*. This is accomplished in Fig **482b** where the tooth T^1 of wheel *A* has fallen onto the impulse pallet *P* to impulse the balance. At the same moment, tooth T^2 is released from locking pallet S^1 to allow tooth T^3 to fall onto pallet C as seen in Fig **482c** where the balance is completing its detached vibration. When the impulse is completed, wheel *A* is locked by tooth T^4 on pallet S^2. The anticlockwise vibration is a mirror image of the clockwise vibration.



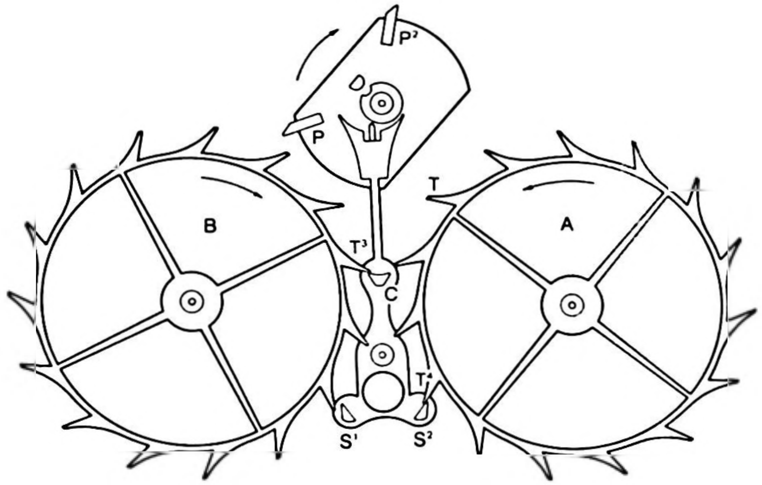
482 Independent double-wheel escapement



482a Balance turning clockwise to unlock wheel *A*


P
T^1
B
A
T^3
C
T^4
T^2
S^1
S^2

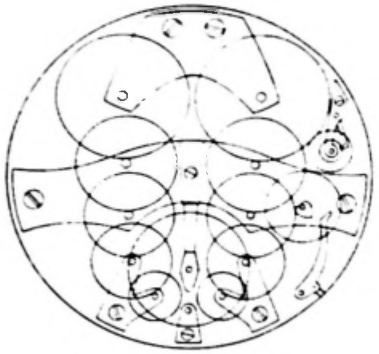
482b Wheel A unlocked and impulsing pallet *P*


P^2
P
T
B
A
T^3
C
T^4
S^1
S^2

482c Completion of clockwise cycle to transfer tooth T^3 to locking C ready for anticlockwise cycle

This arrangement has proved most successful, and a series of six watches was made, the final two being constructed as solar-sidereal chronometers. One of the early examples, carried in the pocket of an independent assessor and laid aside each night during a thirty-day journey to Japan and back, was a little less than one second slow upon return. This may be regarded as a chance performance and certainly not to be expected by design. But a bad escapement could not achieve such a result, which encouraged further consideration of the possibilities.

The arrangement of the movement seen in Fig **482d** would be too complex for a wrist-watch. A further disadvantage is the double unlocking at each vibration, which consumes balance energy. The unlocking forces would be reduced by a half of their value if one side only of the escapement were used in the manner of Robin's escapement. But it would then have only a single impulse at each oscillation of the balance. To set out the escapement see **Appendix II**.

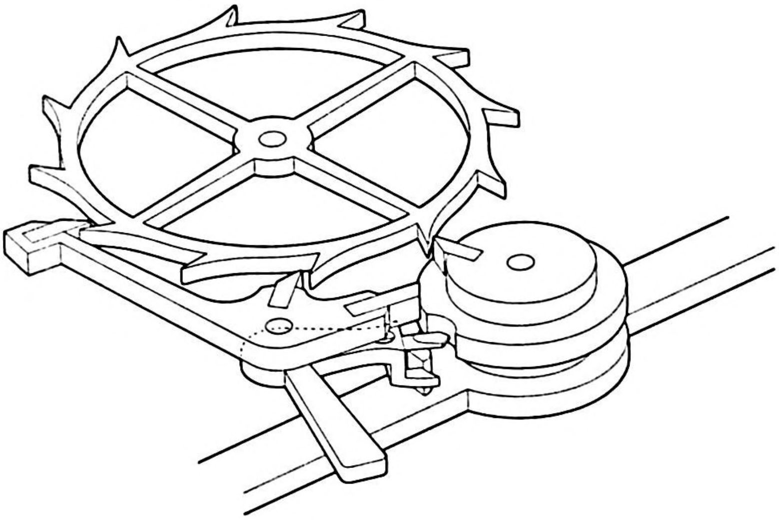


482d Arrangement of independent double escapement train

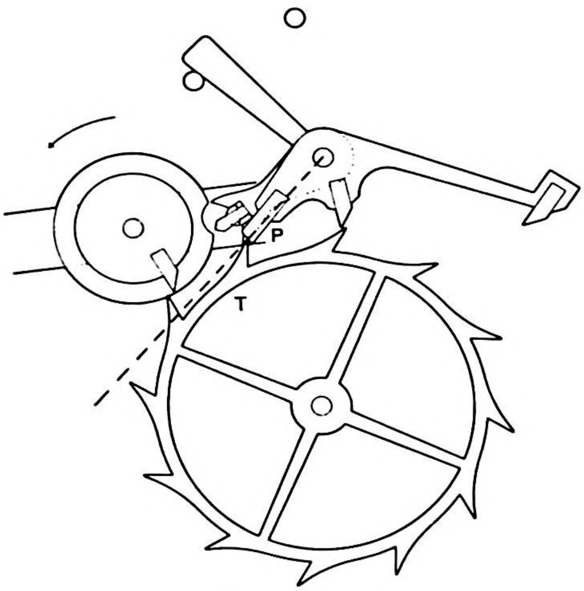
Double Radial Impulse with Single Wheel

When a radial impulse is delivered directly to the balance axis it is essential that the two components are rotating in opposite directions. If an impulse to the balance at each oscillation is required then two escape wheels, rotating in opposite directions relative to each are needed. But it is not necessary for both impulses to be delivered directly to the balance axis. It is only necessary that they are delivered in a radial manner without sliding friction.

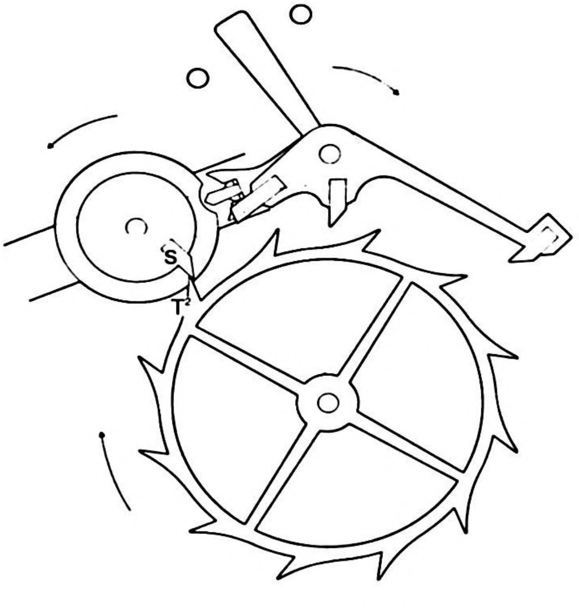
This can be done by using the locking component as a lever to supply the second impulse. Because the movement of the lever is engendered by the balance roller, it must always rotate in the opposite direction to the balance wheel. At alternate vibrations the escape wheel will rotate in the opposite direction to both balance and lever. When the escape wheel is rotating opposite to the balance, an impulse may be given directly to the balance axis by the escape



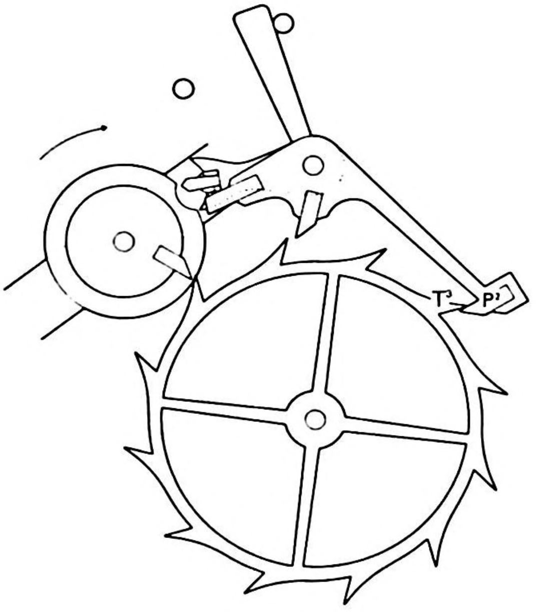
483 Single-wheel double impulse escapement



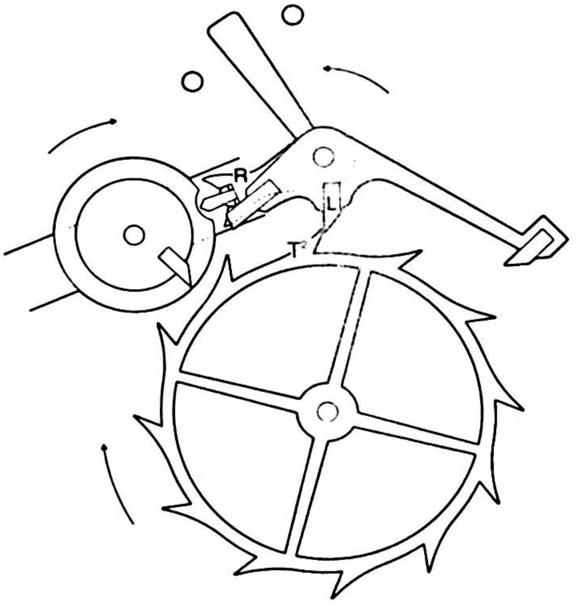
483a Balance turning anticlockwise to unlock tooth *T* from pallet *P*



483b Impulse to balance at *S* from tooth T^2



483c Balance turning clockwise to unlock tooth T^3 from pallet P^2



483d Lift to pallet *L* from tooth T^2 to impulse balance *R* wheel. During the second vibration of the oscillation the escape wheel and lever will be rotating in opposite directions. In this vibration the impulse may be delivered to the lever impulse pallet and to the balance via the balance roller and lever fork. By this means the balance receives a radial impulse at each vibration without sliding action of the impulse surfaces.

The system can be seen in Figs **483a, b, c, d**. In Fig **483a** the balance is turning anticlockwise and about to unlock the escape-wheel tooth *T* from entry pallet *P*. This is completed in Fig **483b** and the escape-wheel tooth T^2 is impulsing the balance pallet *S*. In Fig **483c** the impulse is completed and the escape wheel is locked on lever-exit pallet P^2. On the return vibration shown in Fig **483d**, the balance will again engage the lever to unlock the escape wheel, which will supply impulse from tooth T^2 to the lever pallet *L*. Note that when the balance is receiving impulse, the direction of rotation is opposite to that of the escape wheel, while the lever turns in the same direction as the escape wheel. When the lever is receiving impulse it turns in the opposite direction to the escape wheel.

It can be seen in Fig **483a** that the locking on the entry pallet is not tangential to the escape wheel. This results in increased resistance to unlocking prior to the impulse to the balance. The locking for the exit pallet, Fig **483c**, is tangential but the length of the locking arm also causes high resistance to unlocking.

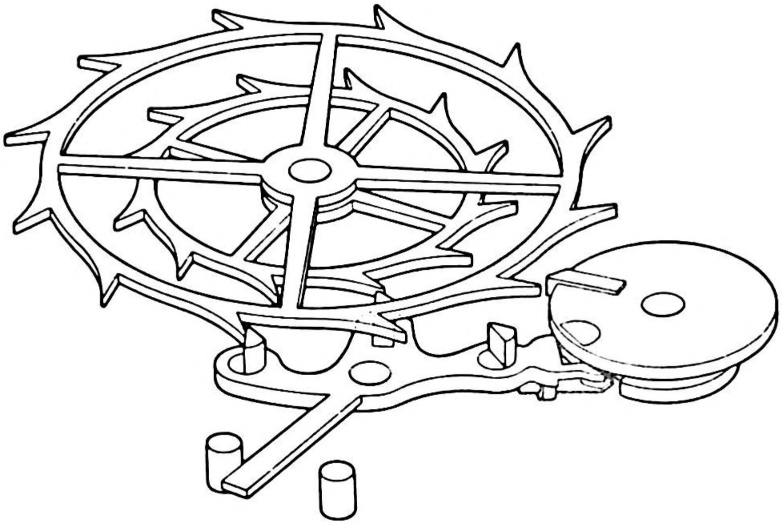
The escaping angle is 30° and because the ratio of balance to lever is 1:1, the lever angle is also 30°. As a consequence, the unlocking impact between the fork of the lever and the balance pin is heavier than is conventionally found with this engagement. But the watch (an Omega 30 mm) has now been running for twelve years without sign of distress to the fork and roller action.

The escapement will always start when wound from the run-down condition. When stopped in the locked position the heavy lockings resist unlocking by the balance roller. The escapement is not suitable for use in a wrist-watch but performs with remarkable regularity as a static timekeeper.

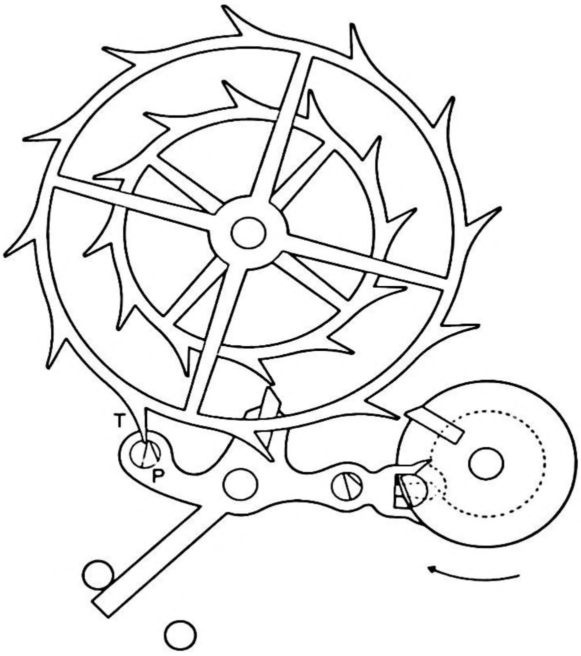
Co-Axial Escapement

Fig **484** illustrates an escapement that avoids the faults of the single-wheel escapement. This employs two wheels, one above the other. The large wheel supplies impulse directly to the balance axis and serves to lock both wheels after impulse. The small wheel supplies impulse to the lever pallet. This escapement allows the use of short, equal radii for the lockings at correct tangents to the escape-wheel circumference and equal force of impulse at each vibration.

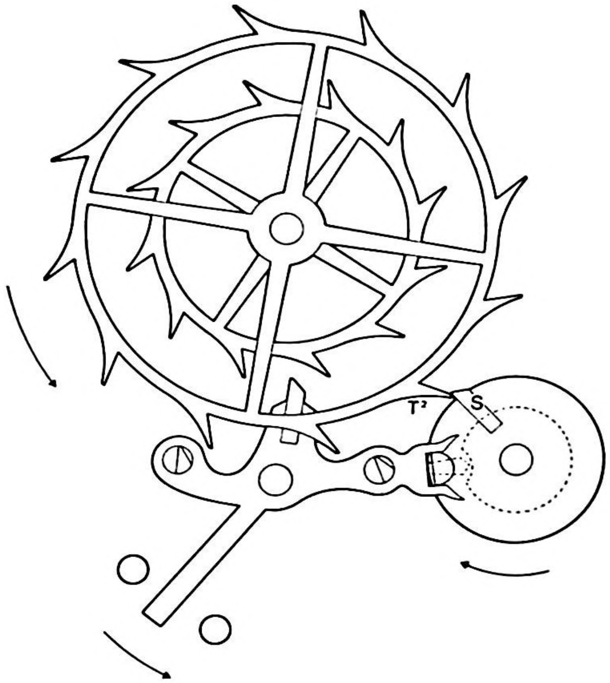
In Fig **484a** the escape wheel is locked by tooth *T* on pallet *P* with the balance turning clockwise to unlock the wheel. This is accomplished in Fig **484b** and the tooth T^2 is impulsing the balance axis at pallet *S*. In Fig **484c**, after the impulse is delivered, the escape-wheel tooth T^3 is locked on pallet P^2 of the lever while the balance completes the supplementary arc. For the second impulse, Fig **484d**, the balance returns anticlockwise to unlock the wheel from P^2 to allow tooth a of the small wheel to supply the impulse to the balance via pallet *L* on the lever. When the supplementary arc of this vibration is completed the position of the components will again be as in Fig **484d**.



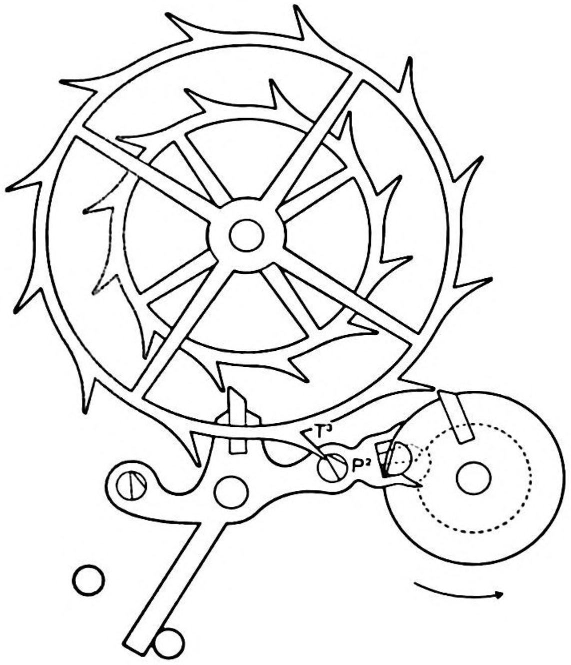
484 Elevation of components of co-axial escapement



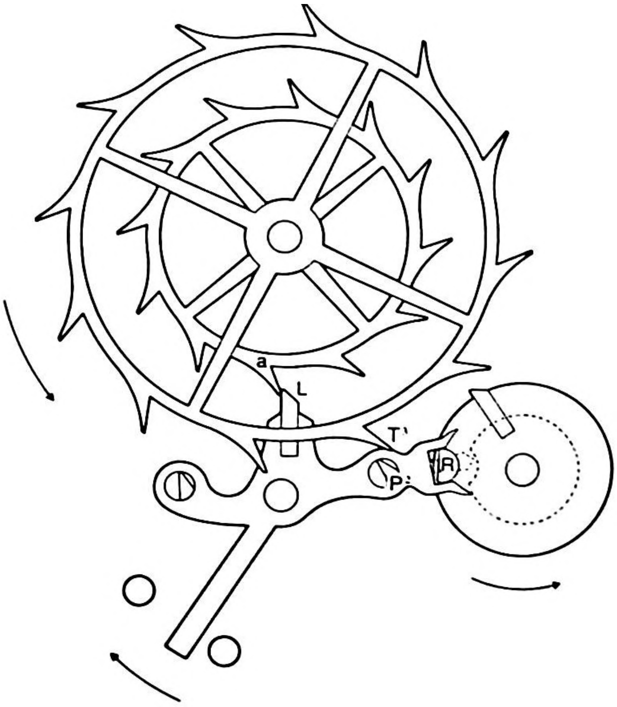
484a Balance turning clockwise to unlock tooth *T* from pallet *P*



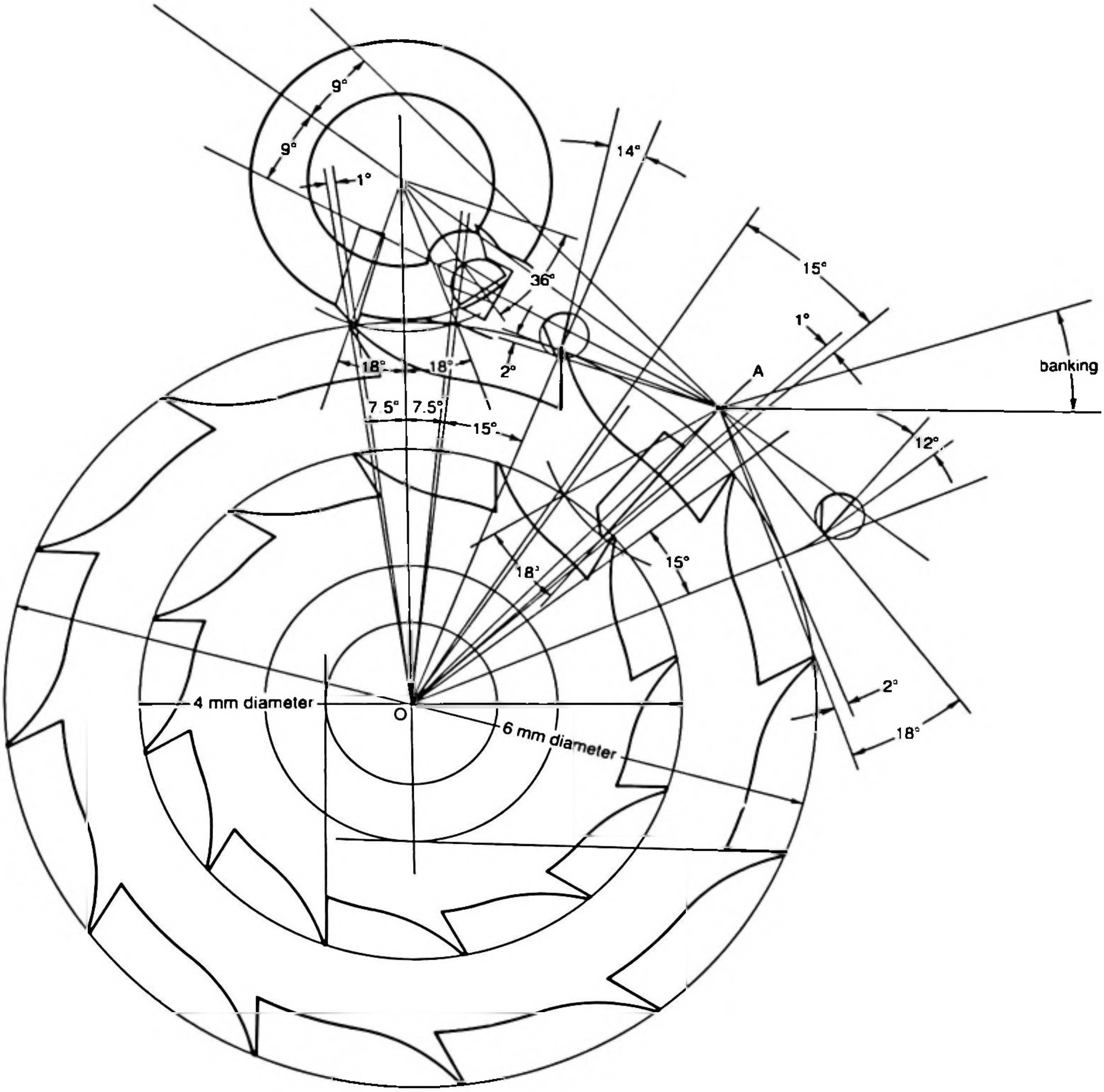
484b Impulse to balance at *S* from tooth *T*



484c Balance turning anticlockwise to unlock tooth *T*³ from pallet *T*²



484d Lift to pallet *L* from tooth *a* to impulse the balance at *R*


9°
9°
1°
14°
15°
36°
1°
2°
A
banking
18°
18°
7.5°
7.5°
15°
12°
18°
15°
4 mm diameter
O
6 mm diameter
2°
18°

484e Co-axial arrangement to 2:1 roller to lever ratio as fitted to Omega 1045

The short, equal radii lockings allow the balance to overcome the locking forces when the mechanism is stopped with the wheel locked. The small wheel allows the lever to be pitched closer to the wheels to ensure tangential lockings.

Note that for security of engagement the lever-impulse pallet does not pass out of intersection with the small wheel radius. This is seen clearly in Fig **484c** with the wheel locked at P^2.

Note also that both balance and lever pallets are radial to their axis, while the locking pallets are set to draw angles as for the lever escapement. Fig **553** shows an example as fitted to a *tourbillon* carriage.

The method of ensuring the safe intersection of the lever pallet cannot be applied to the balance pallet, which must pass out of intersection with the lever for the supplementary arc. Safety can only be assured by increasing the drop of the escape-wheel tooth onto the balance pallet. Fig **485a** shows the drop required to ensure the safe intersection of the balance pallet with the escape-wheel tooth for a wheel of 8 mm diameter.

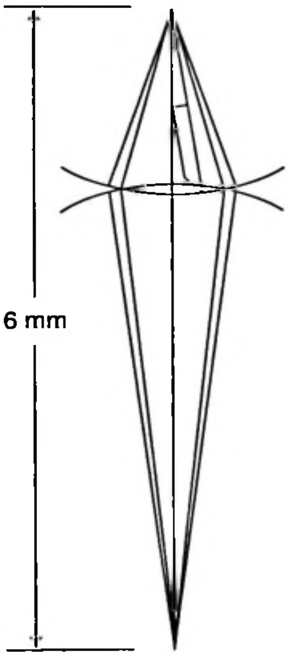
Reducing the diameter to 4 mm for a wrist-watch would make the intersection unsafe unless the drop on to the pallet is increased. The tooth-tip clearance must also be reconsidered because this cannot be reduced in proportion to the size reduction and therefore represents an increased angle and consequent increased loss of impulse.

To increase the depth of engagement of the balance-impulse pallet would necessitate increasing the escaping angle. This would be undesirable for the isochronal qualities of the escapement. It can be seen in Fig **429** that an increase in escapement angle would lead to a decrease in supplementary angle. Since the escaping angle is a net loss of rate it should remain as small a part of the total arc as is possible.

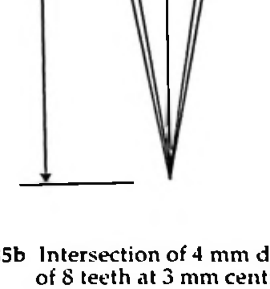
An increase in depth of engagement can be achieved by reducing the number of teeth in the escape wheel. The effect of this is seen in Fig **485a** and **b** where both engagements have a 0.05mm security of engagement after the unlocking and both have a 0.03mm running clearance at the wheel teeth.

With the eight-toothed wheel of 4 mm diameter the useful angle of impulse is preserved while the drop angles remain for the same degree of security.

It is characteristic of the radial impulse to the balance that it involves two drops of the escape wheel for each impulse. The first, which does not occur in the lever escapement, is the drop onto the balance impulse pallet after unlocking. This must be sufficient to ensure that the tooth of the escape wheel falls securely onto the pallet. The second, which is shared by the lever escapement, occurs when the impulse is completed and the wheel tooth departs from the balance pallet to fall onto the locking stone. The same drops occur with the impulse to the lever pallet. The two drops are inescapable and must be accepted. Care in the design of the escapement and close attention to quality will reduce the drops to a minimum.



485a Intersection of 8 mm dia wheel of 12 teeth at 6 mm centres



485b Intersection of 4 mm dia wheel of 8 teeth at 3 mm centres

The consequent reduction in amplitude is simply by comparison with the required initial high amplitude of the lever escapement, which is needed to compensate for the diminution of amplitude with the deterioration of the lubricant. The co-axial escapement will maintain its initial amplitude for long periods and may therefore, with advantage, be set lower.

For a given movement, the characteristics of the two escapements are quite different. The modern lever escapement demands a large escaping angle of 53° and a total arc of some 300°. The co-axial needs only 36° of escaping angle with an amplitude of 270°.

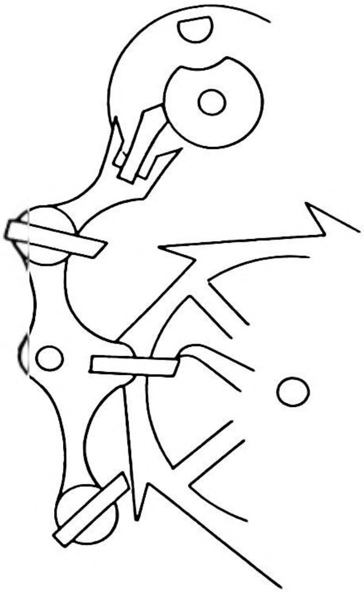
The large escaping angle of the lever is a disadvantage and will reveal isochronal errors as the total arc diminishes. In the vertical positions, the amplitude will fall by some 40° to some 260° at which amplitude negative errors of poise will be revealed. The smaller escaping angle of the co-axial is beneficial isochronally while the vertical amplitude of some 230° will conceal any errors of poise.

For the lever escapement the proportion of escaping angle to total angle is 17.6%. The proportion for co-axial escapement is lower at 13.3%. In the vertical positions, the amplitude will fall by some 40° for both escapements. In this condition the proportion of escaping angle to total angle of the lever escapement will rise to 24%, while the proportion for the co-axial escapement will rise to only 15.6%.

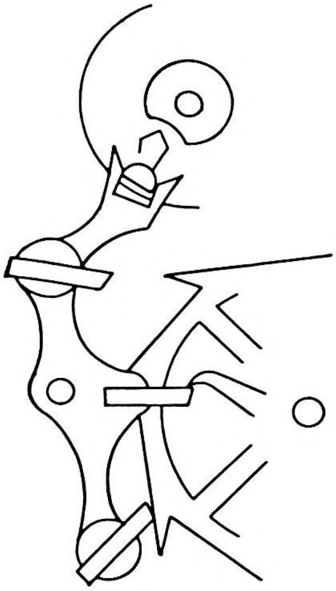
Thus the co-axial escapement with its lower total and escaping angles has better isochronal qualities.

The rules governing the action of the lever-to-roller engagement and the effects of locking radii and draw are as for the lever escapement earlier described. In order to ensure safe and adequate intersection of the balance and escape wheel the balance angle should not be set lower than 36°. A ratio of 2:1 between balance and lever will ensure adequate intersection of the lever impulse pallet with the escape wheel. This will ensure reliability of the guard action if the train is reversed, as for example, when setting the hands of the watch.

In Fig **486a** with an escaping angle of 40° and a lever angle of 25° the escape wheel has been reversed during hand-setting. In this condition the balance can continue to vibrate, carrying the lever with it. If at the position illustrated in Fig **486a** the power is restored to the escape wheel, it will hold the safety dart in contact with the roller to prevent the balance turning. This can be avoided either by reducing the escaping angle or by increasing the lever angle. Alternatively, a compromise could be reached with, say, 36° of escaping angle and 18° of lever angle. By this means the exit locking stone will bank on the back of the escape-wheel tooth before the roller pin can leave the fork of the lever as seen in Fig **486b**.



486a Balance to lever angles of $^{40}/_{15}$ = 2.6:1 ratio



486b Balance to lever angles of $^{36}/_{16}$ = 2:1 ratio

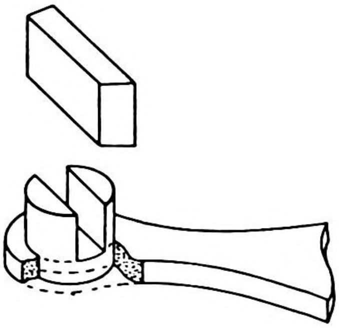
Extra Flat Co-Axial Escapement

The height of the escape wheels of the co-axial escapement was considered to be a disadvantage for use in the very thin watches that are currently fashionable. To overcome this objection, the elevation of the components has been lowered by dispensing with the escape pinion whose function is then performed by the small impulse wheel. The power is transmitted by the train-wheel teeth to the flanks of the wheel in the manner of a conventional pinion. The lift to the lever is delivered by the extended tips of the addendum. As illustrated in Figs **488**, the driving wheel may have its teeth formed with a single ogive to reduce weight to a minimum.

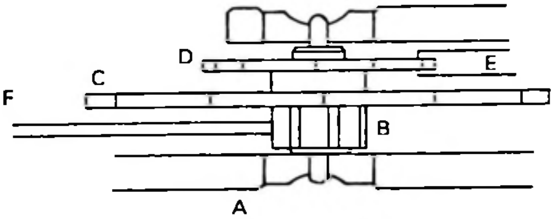
The effect of this arrangement is seen in Fig **487a** where *f* is the driving wheel engaging the escape pinion *B*. *C* is the large escape wheel and *D* is the small wheel. *E* is the lever pallet.

In Fig **487b** F is the driving wheel engaging the small escape wheel *D*. *C* is the large wheel. *E* is the lever pallet.

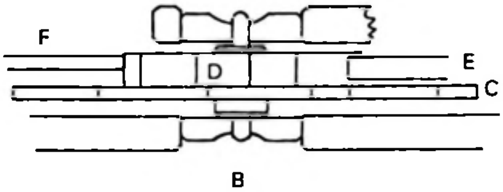
Fig **487c** is the elevation of the complete escapement as fitted to a movement of 2 mm height.



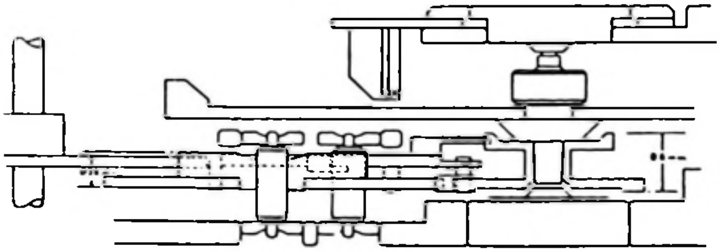
487d Method of fitting adjustable locking stones



487a Escape wheel with conventional pinion

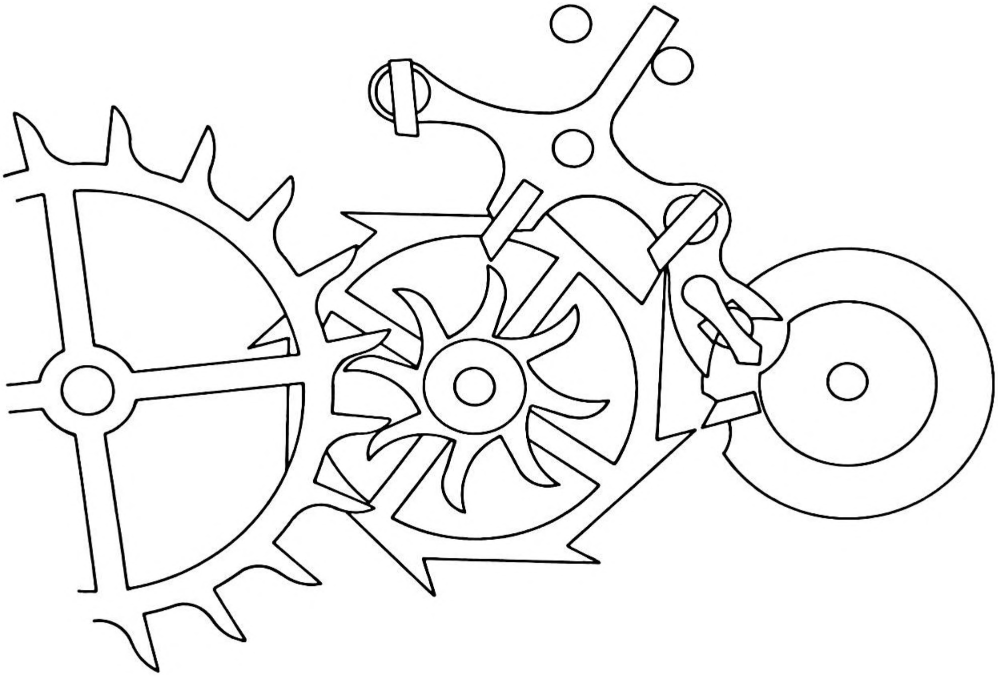


487b Extra-flat arrangement with combined wheel and pinion

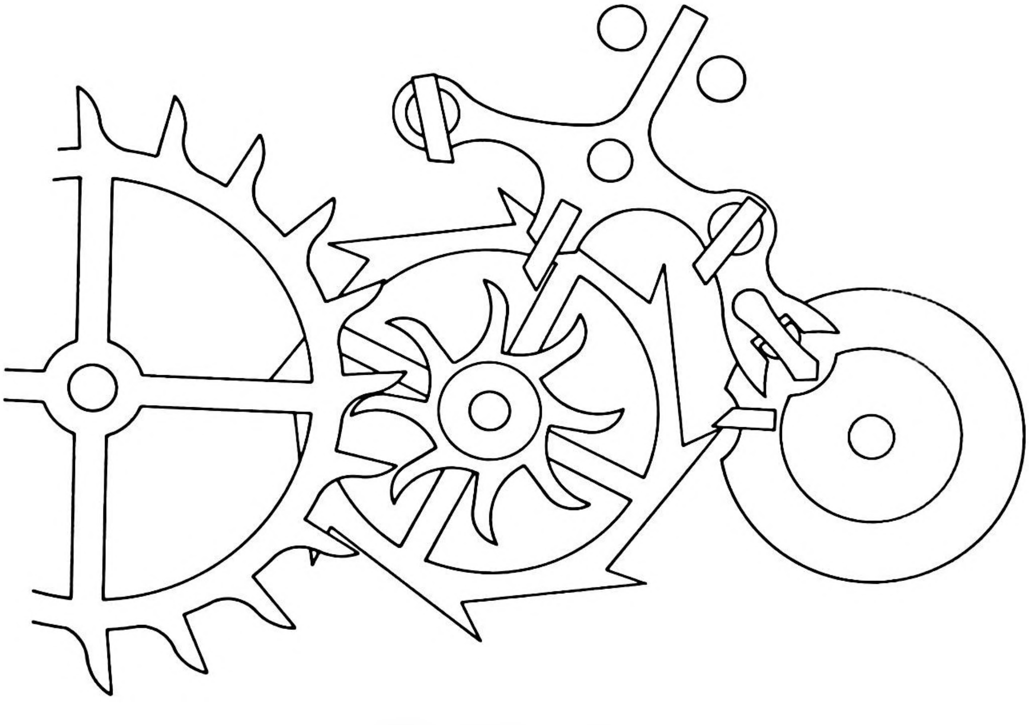


487c Elevation of extra-flat co-axial escapement

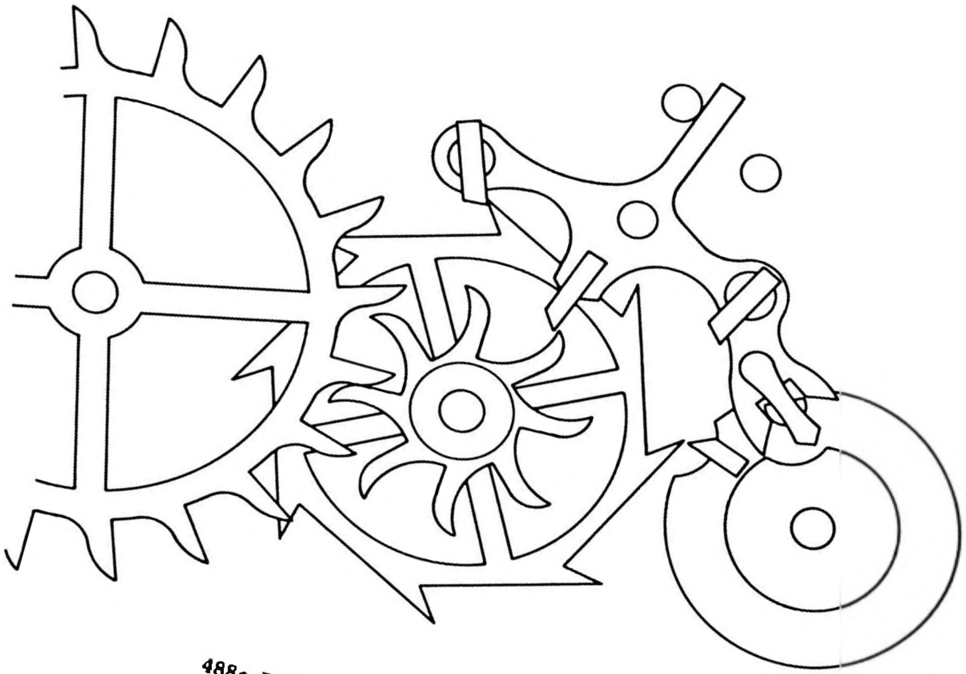
Action of the Revised Co-Axial Escapement



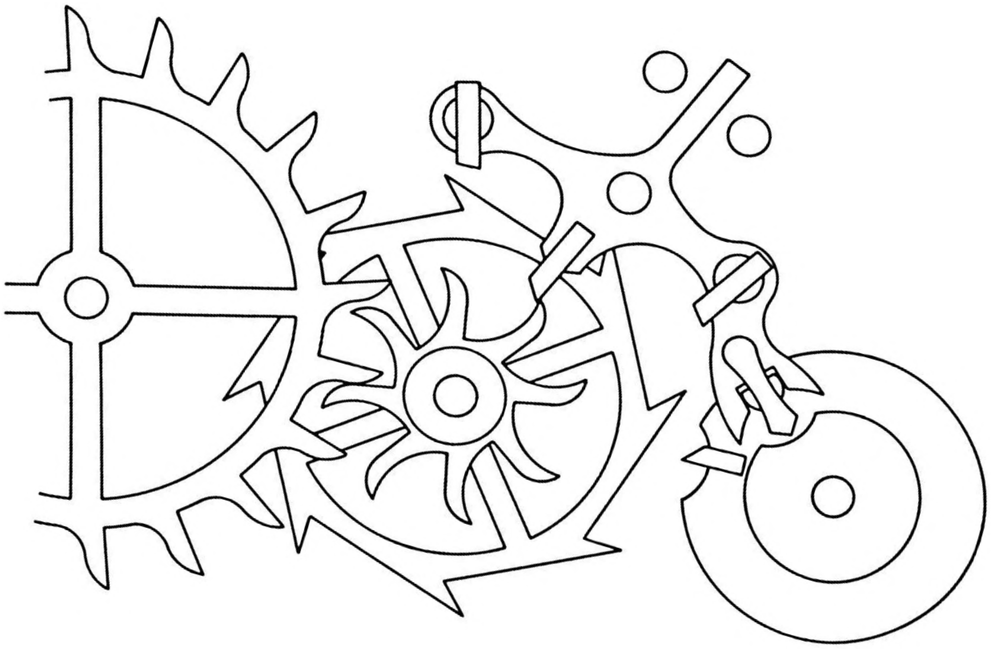
488a Balance turning clockwise to unlock tooth from entry pallet



488b Impulse to balance



488c Balance turning anticlockwise to unlock tooth from exit pallet



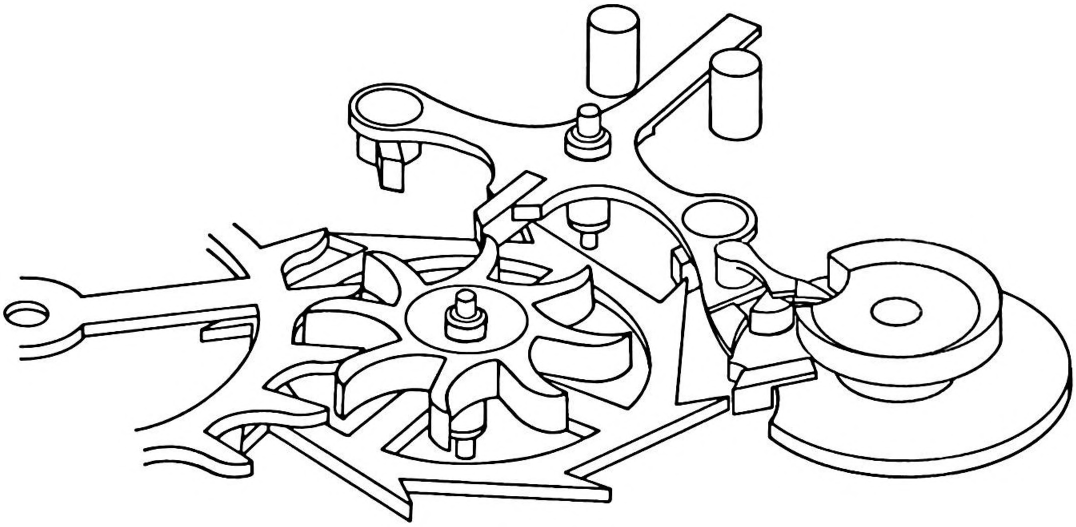
488d Impulse to balance via lever

Allowing 0.12 mm thickness for the large escape wheel and 0.2 mm thickness for the small wheel will produce a co-axial wheel to fit beneath the balance wheel without difficulty (Fig **487c**). The use of vertical ruby locking pins without adjustment for depth was considered to be impracticable in so small an escapement. Therefore the method of fitting conventional pallet stones seen in Fig **487d** was devised to keep weight to a minimum while allowing full adjustment of the depth of locking. The large wheel is close to the plate to bring the lever to the same elevation as the small wheel. This allows the height of the guard pin to be absorbed in the space at the edge of the escape wheel cock while the safety roller fits over the hub of the balance staff, Fig **487c**.

The action of the escapement is as for the earlier examples in which the impulse to the balance is delivered by the larger wheel, Fig **488b**, while the impulse via the lever is delivered by the combined wheel and pinion, Fig **488d**. The two intermediate positions shown in Figs **488** show the wheel locked after the impulses are completed.

For the first of these escapements, fitted to a movement of 2 mm overall height, the escaping angle was increased to 36° for a lever angle of 17°, with the train altered to 21,600 from the original count of 28,800. These thin watches, fitted with small balances and regulator indexes, are not intended to be precision timekeepers but this particular example has been in regular use for ten years without attention and can maintain a usefully close rate.

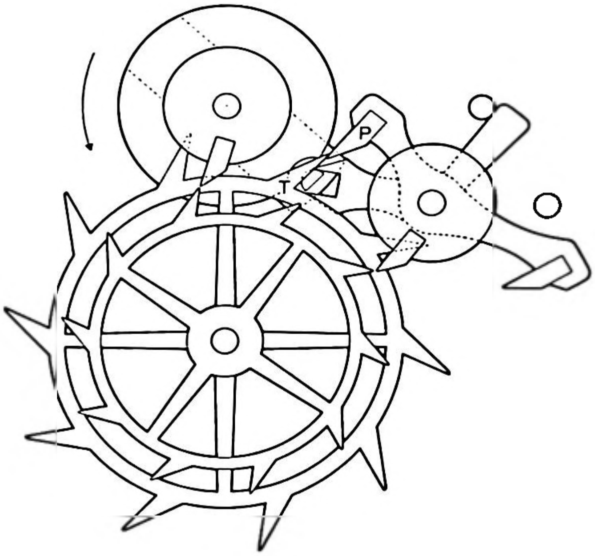
For detailed arrangement see **Appendices I and III**.



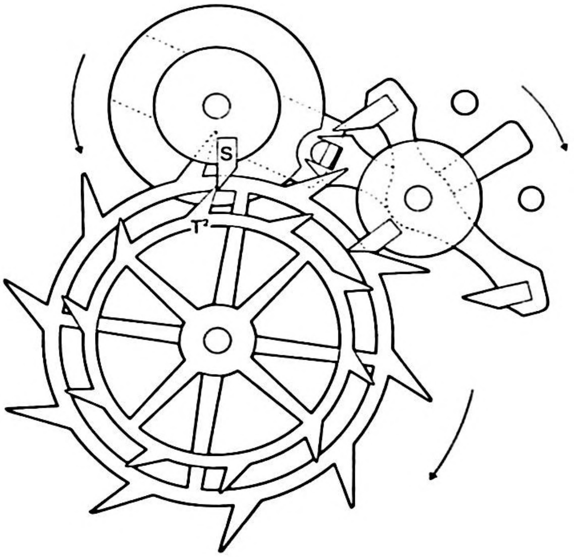
488c Elevation of components

Symmetrical Co-Axial Escapement

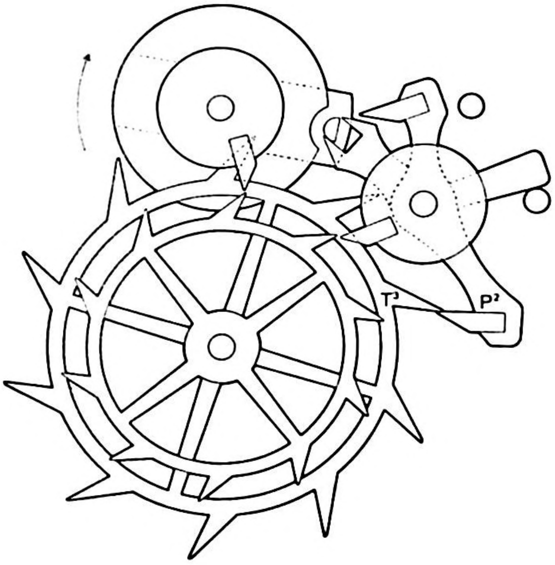
The form of co-axial escapement seen in Figs **489a, b, c, d, e** offers symmetrical impulse at a 32° escaping angle for both impulse to the balance as shown in Fig **489b** and impulse through the lever as shown in Fig **489d**. Each is delivered by the small wheel while the advantageous radius of the larger wheel is used for the lockings of equal radii. The action is as for Figs **488**.



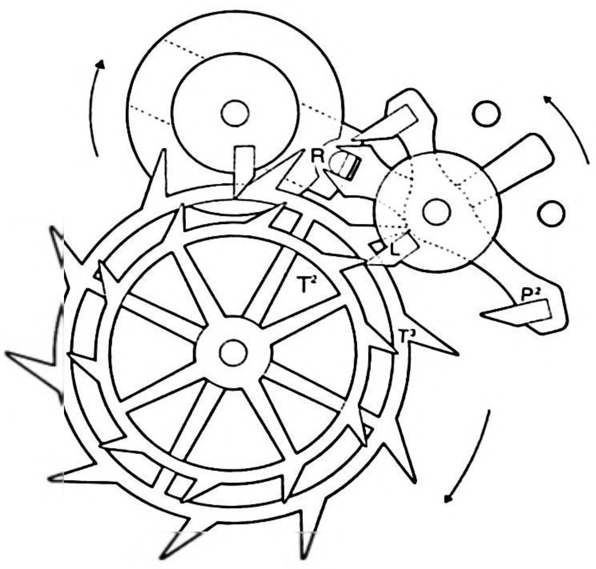
489a Balance turning anticlockwise to unlock tooth *T* from pallet *P*



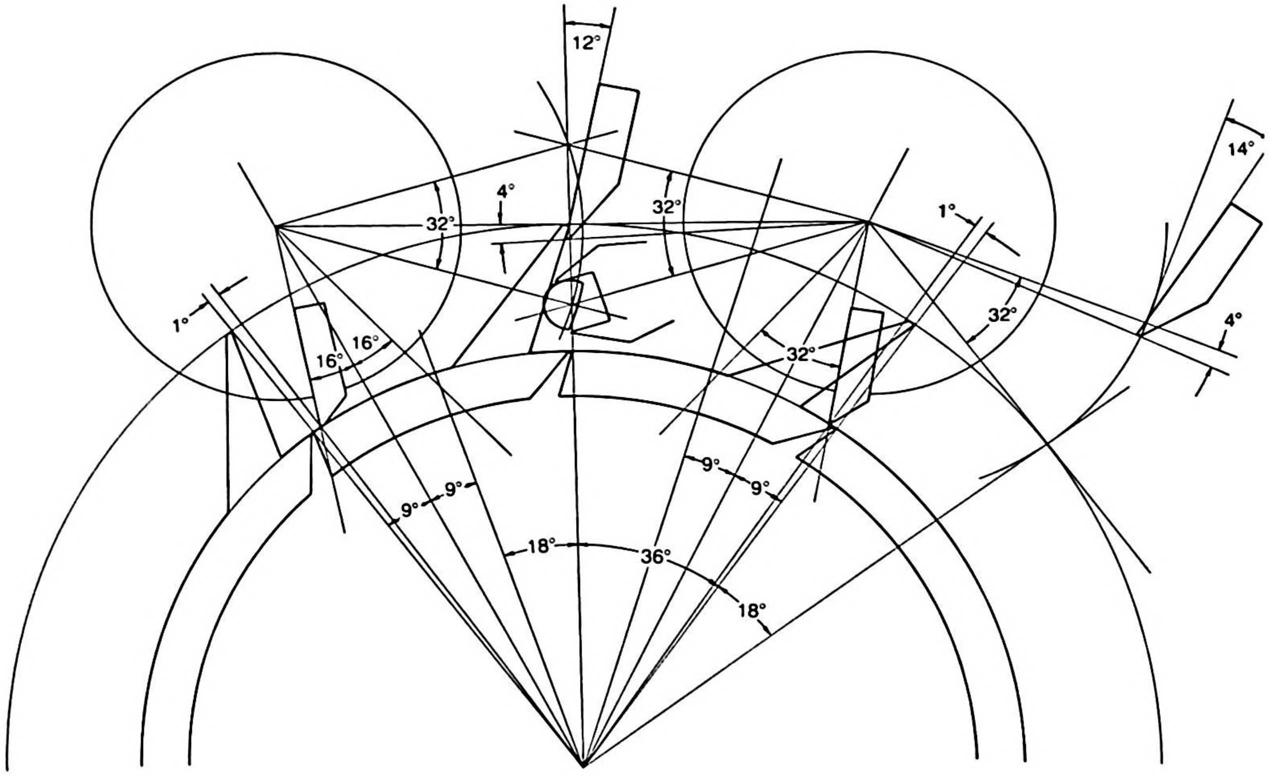
489b Impulse to balance at *S* from tooth *T*²



489c Balance turning clockwise to unlock tooth *T*³ from pallet *P*²



489d Lift to pallet *L* from tooth *T*² to impulse the balance at *R*


12°
14°
4°
32°
32°
1°
32°
4°
1°
16°
16°
32°
9°
9°
9°
9°
18°
36°
18°

489c Co-axial escapement with symmetrical impulse and lockings

9

MAINSPRINGS AND ACCESSORIES

Power Variation

Under perfect working conditions the power of the mainspring will vary in direct proportion to the angle of winding. Each turn will bring a proportional increase in power and each turn of unwinding will bring a proportional decrease in power. To make best use of the power the spring is coiled into a barrel. If, when out of the barrel, the spring has six turns and, when in the barrel, it has twelve turns then it was wound through six turns to fit into the barrel. This may seem self-evident but a greater number of turns are required to fit the spring into the barrel, after which it will relax to fit the space available. The first full winding in the barrel will set the spring to its final number of coils when out of the barrel.

If the spring, out of the barrel, were wound up one turn the effort of turning would be equal to the power available and could be measured as a force multiplied by the radius of the winding lever. If this force is $F \times R$ then the potential power available with the spring in the barrel will be $6F \times R$. The first turn of useful winding will be $7F \times R$ and for six turns of winding the force will be $12F \times R$. At the beginning of the first turn of unwinding the spring has twice the power available as at the end of the sixth and last turn of unwinding.

It is usual for four turns of the barrel to drive the watch for twenty-four hours and so the fall in power is not dramatic. It is also partly offset by the decreasing efficiency of the train as the power increases so that the balance amplitude does not increase in direct proportion to the power. If only two turns were required for twenty-four hours the power drop would be smaller. This could be done by increasing the ratio between the barrel and centre wheel. The increase in ratio would then need an increase in spring power. This would reduce the number of turns of spring in the barrel and consequently the turns of winding available. The gain would be reduced and the stresses disproportionately increased.

If it is necessary to change the available force of the spring this can only be done by changing its thickness. The resistance to flexing, which is the force available from a spring for any given angle of winding, is proportional to:

$$\frac{EWT^3}{12L}$$

E is for the modulus of elasticity of the material and is fairly constant for a given type of material. The number 12 also is a constant applicable to any material of flat section. To the watchmaker only W, the width, T, the thickness, and L, the length, are variable. In a watch, W cannot be increased, for the spring would be too high for the barrel. If it were reduced the spring would attempt to cockle in the barrel and increase the friction between the edge of the coiled spring and inside of the barrel. The force is proportional to the width and if it were required to double the force it would be necessary to double the width.

The force is inversely proportional to the length of the spring and so halving its length would double the force for a given angle of winding. It would also reduce the number of turns available in the same ratio and so the watch would not run a full period. A much greater influence on the balance amplitude can be had by varying the thickness. The force is proportional to the cube of the thickness and doubling the thickness will increase the force by eight times. It will also reduce the number of turns available by a half but with so much extra power the gear ratio could be increased to make fewer turns necessary.

It will never be necessary to increase the force of a spring by eight times. The dimensions of springs and the most suitable numbers of turns have been settled by practical usage. But the watchmaker should leave himself some room for manoeuvre. If the watch under construction is original in design its spring requirements will not be known precisely. The barrel should always be the very largest that can be fitted into the available space. Once the barrel is made, only the thickness of the spring can be usefully altered, but this will require a small change in length to achieve the maximum number of turns available.

Mainspring Dimensions

Ideally, the inner diameter of the unwound spring will equal the outer diameter of the wound spring. The actual length of the spring for a given barrel will depend upon its thickness and the diameter of the barrel arbor. The smaller the arbor the greater the space left for the spring. But if too small, the spring will be over-stressed and become cramped at the inner coils. The ratio of arbor diameter to spring thickness should be about 30:1. Less than 28:1 is undesirable and will shorten the useful life of carbon-steel springs. For a watch arbor a diameter of one-third the inner diameter of the barrel will suit and ensure a sufficient number of turns to give an adequate power reserve.

A barrel of 21.9 mm inside diameter, with an arbor of 7.3 mm diameter, was chosen for the watch illustrated in Plate IV. Six turns of winding are required, of which only four would be used to drive the watch for thirty-two hours. In Fig **491** the arbor occupies one-third of the barrel diameter and the remaining area of the barrel is divided into two equal parts. The dividing line at *A* represents the outside diameter of the wound spring and at *B* the inside diameter of the unwound spring. The two areas are equal and their dimensions are simply found by proportion. If the full diameter is taken as 100 then the arbor will occupy 33 parts of the radius, the wound spring 41 parts and the unwound spring 26 parts. For a barrel of 21.9 mm diameter, 1 part equals:

$$\frac{21.9}{100} = 0.219 \text{ mm}$$

$$26 \text{ parts} = 5.694 \text{ mm}$$

$$\text{and } 41 \text{ parts} = 8.979 \text{ mm}$$

The difference is 3.285 mm or 1.642 mm each side of the arbor.

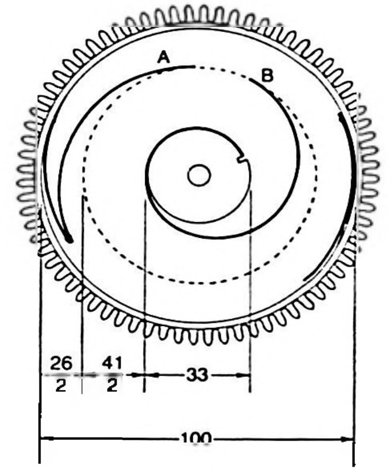
$$\frac{1.642 \text{ mm}}{6 \text{ required turns}} = 0.273 \text{ mm thickness in spring}$$

In practice it was found that a spring of 0.21 mm was sufficient and:

$$\frac{1.642}{0.21 \text{ mm}} = 7.8 \text{ turns were available}$$

This is advantageous because the power drop will be smaller and the spring stresses will be lower.

The spring is a modern cold-worked alloy with high elastic limit. Such springs have a reversed curvature at the outer end and need twelve turns to wind into the barrel. The high elastic limit would allow the use of a smaller arbor to increase the number of turns but they are not needed and the spring is working well within its elastic limit.

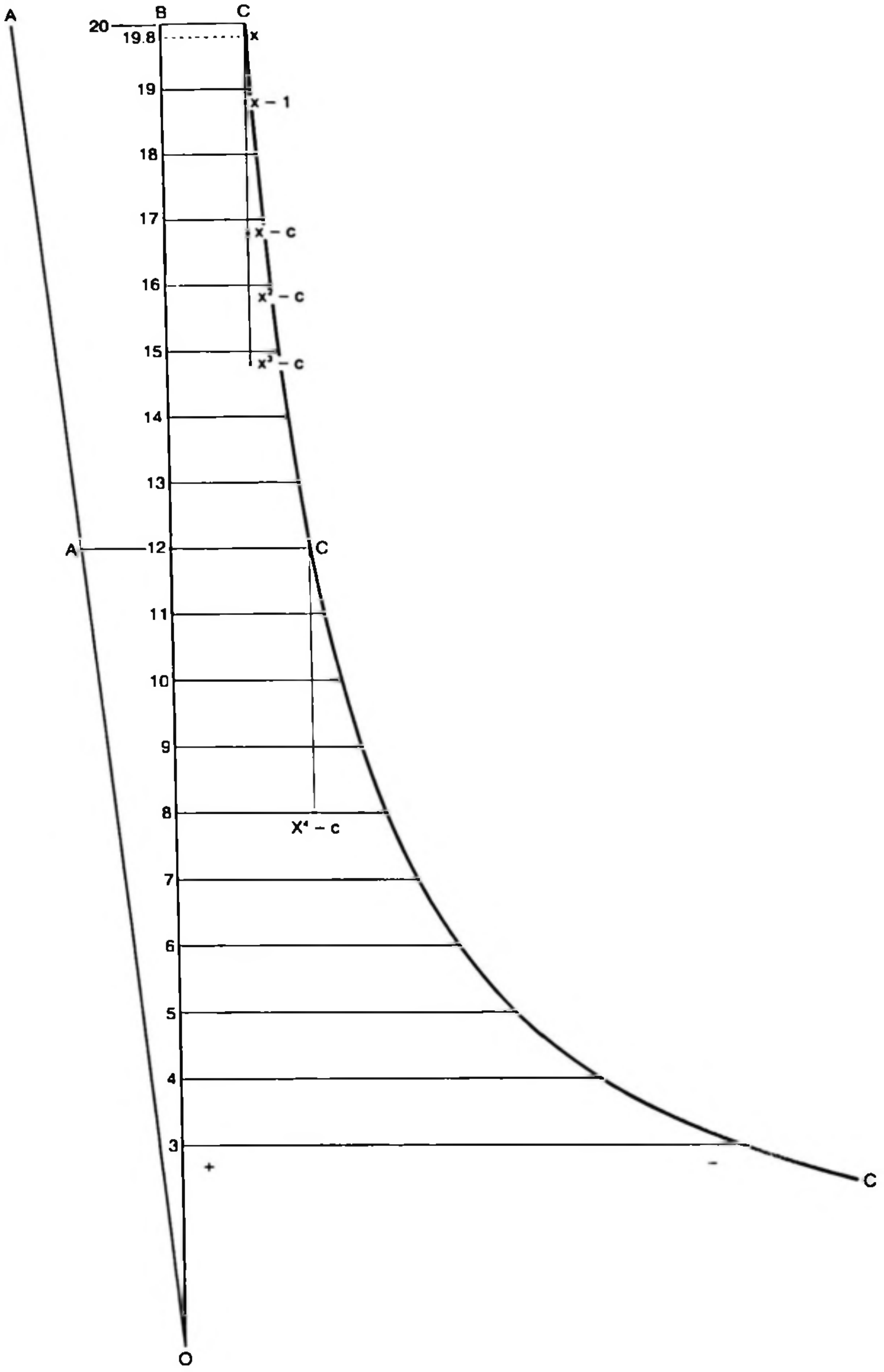


491 Proportions of wound and unwound springs

Spring Power Available

In Fig 492 the angle *AOB* is the total angle of winding of the spring and the column 0–19.8 represents each turn of winding contained in the total angle. The curve *C* represents the power available from the spring at each turn of winding and each turn produces a proportional increase in power. The distance *AB* for each turn of winding is inversely proportional to the distance *BC* for the same turn. Thus $\frac{AB}{A12} = \frac{12C}{BC}$. The spring needs to be wound twelve turns to enter the barrel as shown by line *AC*. After a further 7.8 turns it is fully wound. Only three turns are needed to drive the watch for twenty-four hours. If the spring is fully wound the power drop after twenty-four hours will be about 15 per cent, as shown at *X–C*. The stop work allows four turns for thirty-two hours and at the end of the run the power will fall a further 10 per cent to make a total fall of approximately 25 per cent at X^2C.

A balance amplitude of, say, 260° of semi-arc would be reduced to about 210° by the fall in power. If the stop work were fitted to allow an unused turn at the top of the power curve the fall in power would


A
B
C
20
19.8
x
19
$x - 1$
18
17
$x^1 - c$
16
$x^2 - c$
15
$x^3 - c$
14
13
A
12
C
11
10
9
8
$X^4 - c$
7
6
5
4
3
+
-
C
O

492 Mainspring power curve:

Column *B* shows the number of turns of winding
Distance *AB* shows the power of the spring to be proportional to the number of turns of winding
Curve *C* shows the relative power increase for each turn of winding

be greater at position X^3C. But the power throughout the run would be lower by the distance X^1 so that the difference in power drop at the end of the thirty hours would be very small.

If the spring is too short, each turn of winding will produce a greater increase in power but the number of turns available will be reduced. For a spring producing a total of twelve turns the power will fall off rapidly during the four useful turns by some 50 per cent, as shown at X^4C. Changing the short spring for a thicker one to give the same number of turns will increase the power by increasing angle *AOB*, but the ratios will remain the same and the percentage power fall would be the same.

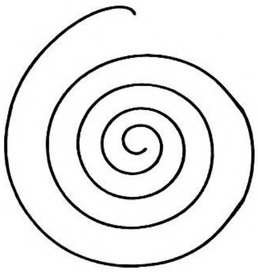
The power curve of the spring cannot be plotted exactly, as shown in Fig **492**, by measuring the resistance to turning after each additional turn of winding. The friction of the coils is variable between winding and unwinding due to the different direction of rotation. The speed of rotation of the barrel will also affect the friction of the coils and a fast-turning barrel will offer less friction. This is particularly so where the spring is made very long and weak in order to produce many turns. Temperature and lubrication will also affect the power. In the long term a molybdenum grease will be the best lubricant.

Type of Mainspring

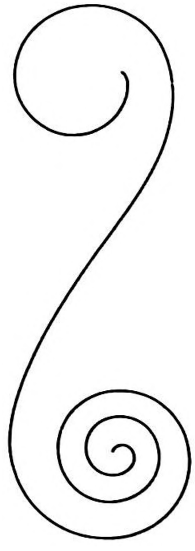
The centre wheel of a watch may be driven by a spring producing one turn in twenty-four hours at high power or twenty-four turns in twenty-four hours at low power. The former will have a destructive force when fully wound which will rapidly diminish during the running period. The latter will produce a variable power which will be insufficient to drive the watch reliably. As in all branches of horology a compromise is necessary and the solution to this problem has been reached by successful practical experience of the requirements of a modern, going barrel watch.

Fig 492 shows that stop work can increase the power variations by preventing the use of the top turns of the spring. In actual practice the reverse will occur with a carbon-steel spring of the type commonly found in old watches with stop work. The stop work should be fitted to prevent the last turn of winding coming into use. This will prevent the spring being over-stressed and becoming cramped so that the number of turns needed to fit it into the barrel is reduced. A reduction in the number will bring the first turn of winding lower down the curve, with consequent increase in power loss during the twenty-four hour run.

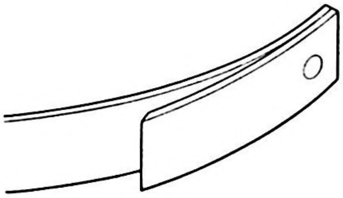
Modern steel-alloy springs have greater elasticity and can be fully wound without distress. A further useful feature of these springs is the reverse curvature of the outer half. Figs **493a** and **b** show the difference between the form of a good-quality, carbon-steel spring, **a**, and a steel-alloy spring, **b**, after the same period of use. The effect of the reverse curve is to increase the power from the outer half by winding it through a greater angle than the inner half. This increase in power holds the wound inner coils closer to the arbor and reduces the friction of unwinding by unwrapping from the outer



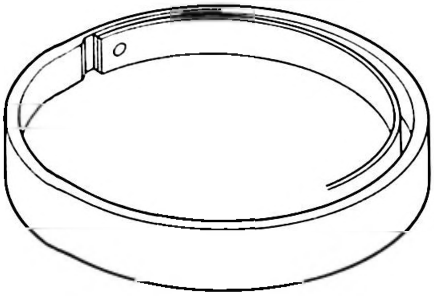
493a Carbon steel spring



493b Steel-alloy spring



494 Mainspring hook



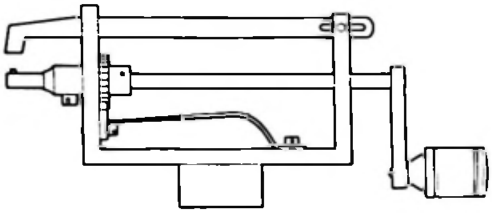
495 Recessed barrel hook

end. The reverse occurs with a conventional spring in which the inner coils are wound through a greater angle and suffer higher stress. Mudge achieved much the same effect by tapering his springs towards the centre so that the inner coils were weaker.

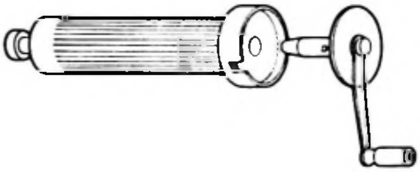
Hooks and Fitting

The form of mainspring hook shown in Fig **494** is simple and strong. The hook is riveted to the spring and the rivet head filed flush with the surface. It has the slight disadvantage that the thickness of the hook occupies useful space in the barrel. This is not important if sufficient space is allowed for a large-diameter barrel and, in any case, the hook can be let into the inner surface of the barrel wall, as in Fig **495**. The slight resilience inherent in the free end of the lamina is useful for relieving the barrel teeth of extra pressure when the spring is fully wound and without stop work.

To avoid distortion of the spring while fitting into the barrel a winder should be used if the height of the spring exceeds one-eighth of the diameter of the barrel. The simple winder shown in Fig **496** will suit for most sizes of barrel. Wind the spring on to the arbor, place the barrel over the exposed end, reverse the ratchet and unwind into the barrel. For smaller springs the system shown in Fig **497** is easier to use. The spring is fully wound into the barrel by the arbor with a handle. The mainspring barrel is placed over the open end and the spring is ejected from one into the other. These winders should not be used for barrels with steel hooks because the force of the expanding spring will cause the hook to distort the barrel wall.



496 Mainspring winder for large springs



497 Mainspring winder for small springs

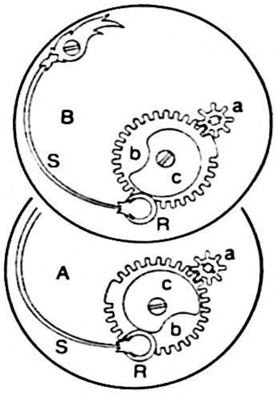
Equalizing the Force of the Spring

When only the verge escapement was available for use in spring-driven timekeepers it was important to equalize the force of the spring in order to avoid excessive variations of timekeeping. With the introduction of the cylinder escapement with its improved lockings, variations in power were less disturbing to the rate. Detached escapements are still less affected by power variations so that a great change in power will cause only a small change in rate.

For general use with modern escapements the methods of springing and adjusting watches have eliminated the necessity for constant power so that aids to this end are no longer used. But the watchmaker may see the need for reintroducing one or more of the earlier methods which were, at one time, universally used and which he will meet frequently enough to want to be able to understand.

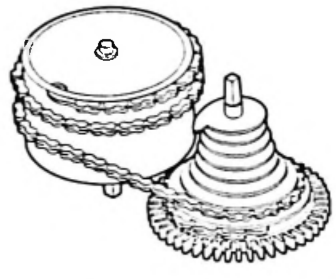
Fusee and Stackfreed

The two historically common methods for equalizing the force of the mainspring at the centre pinion employ the fusee or the stackfreed. The latter was used only in Germany in the sixteenth and seventeeth centuries. It is illustrated in Fig **498**, *A*, in the usual form found in old watches. The wheel *a* is fitted to the spring arbor and engages the wheel *b* which carries the cam *c*. When fully wound the blank tooth acts as a stop, with the highest part of the cam under the roller *R* of the spring *S*. This will extend the spring to the position shown at *B* and exert considerable friction on the pivot of wheel *b* to absorb some of the power of the mainspring. During unwinding the cam will slowly relieve the pressure of the stackfreed spring to release more of the dwindling power of the mainspring. The negative curve at the end of the cam lift is meant to help the mainspring when at its weakest.



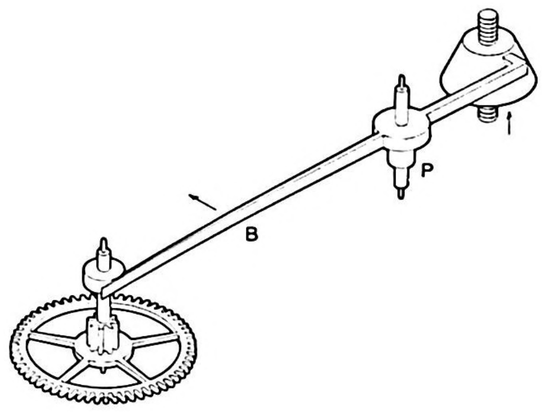
498 German stackfreed

The origins of the stackfreed are unknown and it may have preceded the fusee shown in Fig **499** which consists of a tapered spiral pulley connected to a mainspring barrel by a chain or cord. The chain is wound from the barrel on to the fusee so that the smallest radius accepts the greatest power. During unwinding the chain pulls at an ever-increasing radius to compensate for the reducing power of the spring. When fully wound a stop lever is lifted by the rising chain to catch a projection on the fusee and prevent further turning.



499 Fusee with chain

The stackfreed found no favour with the French or English, who later dominated the field of watchmaking. Presumably it was not satisfactory but as the friction is proportional to the pressure it should have worked. Stackfreed watches have high-geared trains and powerful mainsprings and it may be that the forces are too great to balance without harshness entering in to cause variations in the action. If the stackfreed worked it would have the merit of occupying unwanted space, whereas the fusee takes up useful space.



500 Modified stackfreed

The system shown in Fig 500 is based upon the principle of the stackfreed. The cam is the cone which forms part of an up and down indicator. The pivoted component *P* is turned by the cam to press its thin spring extension into the arbor of the fourth wheel. The pressure is highest when the cone is up and the mainspring is fully wound. As the spring runs down the pressure is released and more power allowed to reach the escapement. The thickness of the spring brake *B* can be adjusted to hold the balance arc constant throughout the run. The system will need many years of running before it can be recommended as reliable, but it may be worth experimenting with.

The Shape of the Fusee Cone

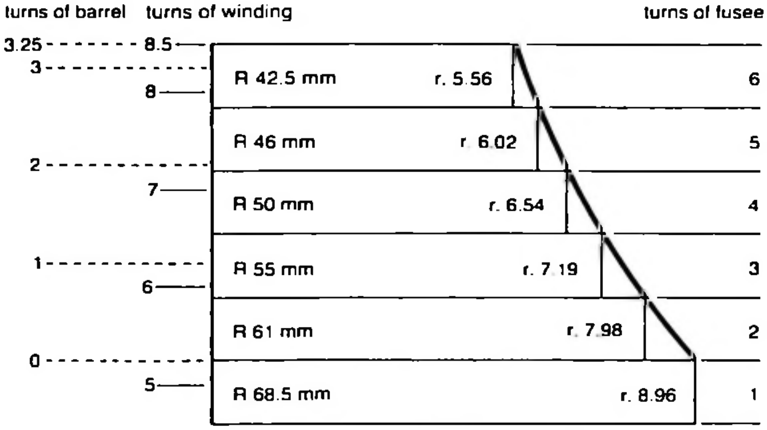
The fusee watch needs a stronger mainspring than the going barrel watch for the same balance amplitude. The end of the last turn of unwinding of the fusee must have the same power as the beginning of the first turn of unwinding of the going barrel watch. This means there will be fewer turns in the barrel and the power curve will start lower down, as in Fig 492.

The shape of the fusee must compensate for all variations in power of the spring. It cannot be precisely arrived at by calculation because the required strength of the spring is not known. The fusees of lever watches have greater curvature than the fusees of verge watches which have weaker springs with more turns in the barrel.

The problem for the watchmaker is to produce a system that will be directly applicable to the watch in the course of construction. The practical solution is to devise a correctable compromise. Once the dimensions of the watch are known the diameter of the fusee wheel and barrel can be determined as the basis for forming the fusee. To take a practical example, a watch movement will be 58 mm diameter with a lever escapement. For thirty hours' running, with a fusee wheel of 60 teeth and a centre pinion of 12 leaves, the fusee needs 6 turns. A fusee wheel of 25 mm diameter and a pinion of 5 mm diameter will fit comfortably in the frame. The barrel must be the largest possible because a powerful spring will be needed and this will limit the number of turns available. The barrel may overlap the centre pinion but must leave room at the centre arbor for the chain to pass. Allowing 1.0 mm for the chain and 1.5 mm diameter for the arbor, a barrel of 26 mm diameter would suit with a mainspring of 0.3 mm thickness. The largest diameter of the fusee cone will be smaller in diameter than the barrel and all subsequent turns are smaller still. The barrel will make fewer turns than the fusee.

We shall decide on 5.25 turns from the spring but use only 3.25 turns of the barrel for 6 turns of the fusee. With the spring in the barrel, wind it tightly to set the coils. When unwound count the number of turns and remove the spring from the barrel. If there are 10 turns in the barrel and 5 out, then it is wound 5.25 turns when in and set up for use.

From Fig 492 draw the curve for 5.25 turns to 8.5 turns. This is



501 Computation of the fusee curve

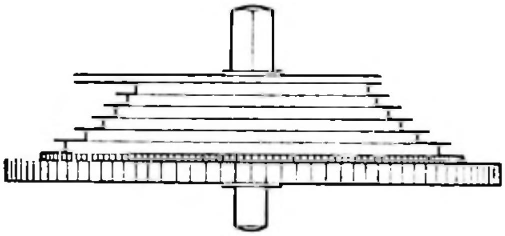
shown in Fig 501 divided into the six radii of the fusee. The sum of the radii (R) × 2π = 2029.47 mm, the length of chain required for 6 turns at the scale shown in Fig 501.

The circumference of the barrel multiplied by the turns of winding is $26 \times \pi \times 3.2 = 265.464$ mm which is the length of chain required for six turns of the fusee at actual size. The scale of Fig 501 is found by:

$$\frac{2029.47}{265.464} = 7.64$$

It remains only to divide each radius of Fig 501 by the scale to find the actual radii of the fusee to produce a total length of chain equal to 3.25 times the circumference of the barrel. If preferred the force of the spring can be measured at equal increments to find the force per turn and the ratio of top to bottom radii. But the resultant force curve must be re-divided into the number of turns of the fusee.

The final form of the fusee curve will depend upon the dimensions of the watch frame. A large watch with a powerful spring will need a thick chain and consequently a higher cone than a small watch. For a fusee wheel of 25 mm diameter a chain of 0.5 mm will be needed with a guide flange of 0.12 mm making a total of 0.64 mm. This would require a cone 4.0 mm high. Fig 502 shows the fusee derived from Fig 501 and with dimensions to suit a watch

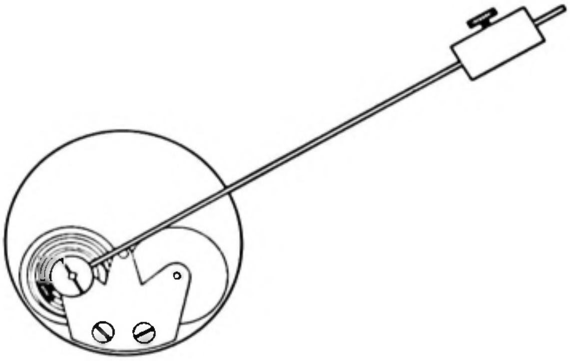


502 Fusee derived from Fig 501

movement of 58 mm diameter. These proportions would be suitable for a movement of some 6.4 mm between the plates. For a smaller watch the chain would be thinner and the fusee commensurately lower to make a thinner watch.

Equalizing the Force

The force at the smallest and greatest turns can be equalized by setting up the mainspring using the adjusting rod. This is shown in Fig 503 fitted to the fusee arbor. Wind the watch fully and adjust the weight to counterbalance the force of the barrel. Alter the set-up to equalize the force of the last turn of unwinding. If the pull is too great at the small end, change the spring for a weaker one that will give more turns in the barrel. If the pull at the large end is greater the spring is too weak. It is safer when cutting the fusee to leave the small end slightly oversized so that power at the large end can be equalized by setting up the spring. If necessary, it can later be reduced in the fusee engine to suit the spring.



503 Fusee adjusting rod

Setting up the spring for the first turn of winding will increase the power throughout the turns of the fusee. This means in effect that the small turns are too large in diameter. The difference will be found to be very small and is useful in allowing for final correction of individual turns to suit the wound spring characteristics.

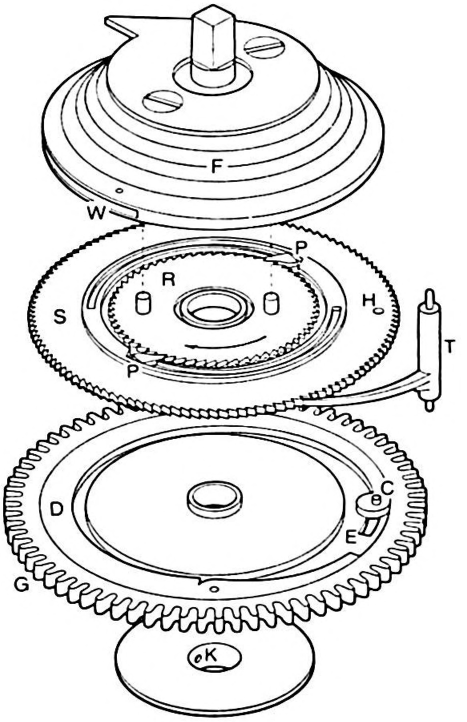
If a precise adjustment is required a final check should be made by observing the balance amplitude at four-hour intervals as the spring runs down.

Fusee Maintaining Power

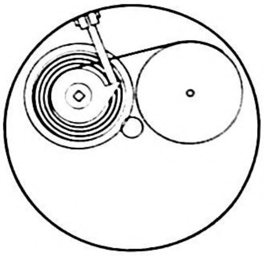
During winding, the power is lifted from the train of a fusee watch and some form of maintaining power is necessary to keep the watch running. Harrison devised the method shown in Fig 504 which, although complex in construction, has survived to the present day.

The ratchet wheel *R* is fixed to the face of the large end of the fusee cone *F* and is pulled by the chain in the direction of the arrow.

Through the pawls *P* it turns the steel ratchet wheel *S*. The hole *H* accepts the pin *C* of the spring *D* recessed into the great wheel *G*. In turning, *S* winds the spring *D* until the lower end of pin *C* meets the limiting end of slot *E* and the power of the mainspring is transferred to the great wheel to drive the train. When the fusee is turned against the arrow to wind the chain back on to the fusee cone, the steel wheel *S* cannot follow because the pawl *T* pivoted in the plate is constantly engaging its ratchet teeth. This maintains spring *D* in tension to continue to drive the great wheel during winding.



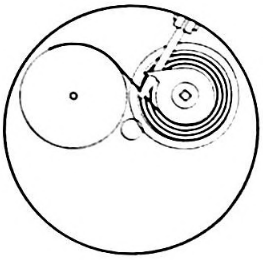
504 Component parts of the fusee



505 Normal fusee stop work

Reverse Fusee

It is usual in fusee watches for the fusee to be placed to the left of the barrel when viewed from the back, as in Fig 505. In this arrangement the pressure on the pivots of the fusee is the sum of the force at the centre pinion and the tension in the fusee chain. If the positions of the fusee and barrel are reversed, as shown in Fig 506, the pressure is divided between the centre pinion and fusee pivots. The arrangement seems to have been used first by Mudge in his marine timekeeper. It was rarely used by English makers who, because of conditions of work and trade, rarely took up new ideas. But it is surprising that the individual makers such as Arnold and Earnshaw, who designed their own movements, did not see its advantage.



506 Reversed fusee stop work

Constant Force Escapements

In the constant force escapement the impulse to the oscillator is delivered by a separate, small detent, either spring or pivoted with spring. After each impulse to the balance the detent releases the escape wheel which re-sets it on its catch ready for the next impulse. To avoid variation of force due to change of temperature, some form of compensation is needed for the detent. It would nowadays be sufficient to make it of Elinvar which retains constant elasticity with change of temperature.

Such escapements do not fulfill their promise and their rate of timekeeping is not better than a conventional detent escapement. The constant blow of the detent against the impulse pallet, always at the same spot, seems to induce inconstancy of action. This, together with the disadvantage of the delicacy of the components, makes them unsuitable for watches.

Remontoir

A small spiral spring, intermediate to any two wheels in the train and wound at regular intervals by the mainspring, will supply a constant power to the escape wheel. Impulse can be delivered in both vibrations of the oscillator by the conventional escape wheel so that the defects of the constant force detent do not arise.

If the *remontoir* spring is between the escape wheel and its pinion then it will need to be released at each vibration. This would be inconvenient in a watch in which limitations of height would necessitate unacceptably delicate components. The watch illustrated in Plate II employs a *remontoir* released at fifteen-second intervals. The spring is of Elinvar to avoid the effects of temperature change on its elasticity.

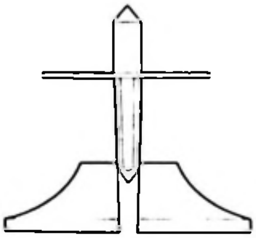
The use of the *remontoir* is by far the best method of smoothing the power supply, but it is complex and costly to make. For this reason watches with *remontoirs* are very rare and this, combined with their attractive action, gives them a special place in the affections of the connoisseur of mechanics. The fact that the mechanism is quite unnecessary merely adds to its charm.

Making the Fusee

The Brass Cone

Prepare a brass disc for the cone, leaving it oversized in length and diameter. Drill through for the fusee arbor and broach the hole to a taper. Fit to a tapered arbor in the lathe and make the faces true with the hole. Turn the cone approximately to shape leaving all diameters oversized.

The Steel Arbor


507 Fitting the fusee steel

Form the fusee arbor from carbon steel. File the lower length hexagonal in shape and to the same taper as the hole in the brass. The small end of the hexagon must just fail to enter the large end of the hole in the brass, as in Fig 507. Note that in this instance the flange for the stop piece is formed in one with the arbor. This may be fitted separately, either with screws fitted into the brass or threaded directly on to the arbor.

The upper face of the flange is the height of the top pivot shoulder. The face of the flange will later be reduced to provide running clearance in the frame. Measure from the face the position of the cap hole *K*, Fig 504, and add sufficient to allow for cleaning and polishing the top pivot after hardening. Drill the hole and broach tapered.

To reduce the work to be done after hardening, file the square and turn the pivots but leave all dimensions oversized. File the stop flange to shape. Harden in oil and temper just sufficiently to allow final turning and filing. The pivots must be left as hard as possible to withstand the pressure of the mainspring.

Fitting the Wheels

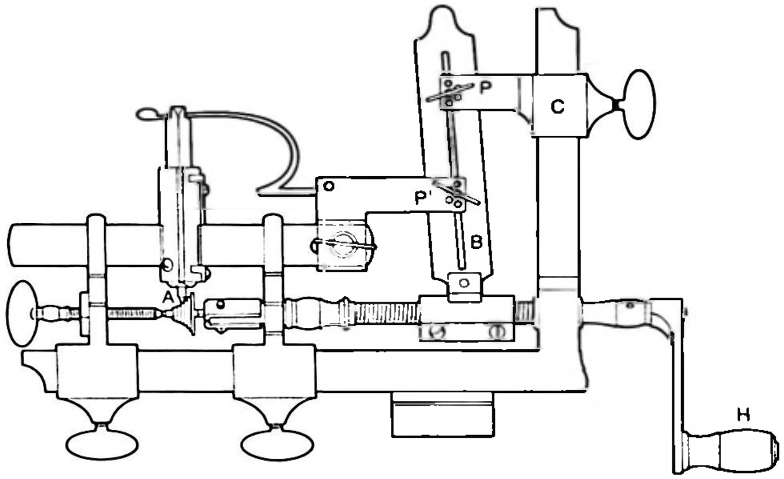
Fit up in the staking tool and drive the taper into the brass. Finish the pivots to length and diameter and make the square to size. Mark the large end of the cap pin hole with a knife file across the diameter. Open the hole in the ratchet wheel to fit the arbor and drill through into the fusee at two diametrically opposite and differing radii. The difference in radii will help to locate the wheel correctly after removal. Open the centre hole further to receive the boss of the maintaining wheel and finally pin the ratchet wheel to the fusee. Fit the great wheel and maintaining spring and finally the cap and pin. The cap face is reduced a little at a time until, with the pin fitted, the great wheel and maintaining wheel can be turned freely but without looseness. Finally finish the cone to shape checking the radii against the drawing while allowing for a reduction of half the width of the chain or cord when the groove is completed to depth.

Cutting the Spiral

To avoid possibility of damage it is important to finish all the fitting work before cutting the spiral groove. This is done in the fusee engine, shown in Fig 508. The cutter *A* is a sliding fit in its guide and can be kept in contact by finger pressure from above. Turning handle *H* will advance the nut of beam *B* along the left-hand thread and advance the cutter along the spiral. The ratio of rotation of the fusee to advancement of the cutter can be varied by adjustment of bracket *C* and pins *P* and P^1.

Start the cut at the largest diameter. Use a flat-faced cutter without top rake. Finish the edge square for a chain, and round for a cord. Several light cuts will be needed before the full width of the cutter will be in contact. At the end of each cut withdraw the cutter and reverse the rotation of the handle to return the cutter to the beginning. By this means damage to the groove edges due to backlash in the tool will be avoided. When the cut is the full width for the whole length of the spiral it should be examined for irregularities of radius. These can occur in the early stages when only the corner of the tool is in contact. Correct them by removing a little at a time from the high places. When the depth is uniform continue with complete cuts to the required depth. The larger turns will require more pressure to cut than the smaller turns. Vary the pressure of the cutter as it travels along the groove and take care that the small end does not reduce too quickly. Finally, with a small cutter in the lathe, make the slot for the hook and fit the hook pin, as in Fig 504, *W*.

The groove can be cut in the lathe if a screw-cutting attachment is available. Rest the cutter against a bracket fitted to the slide rest and apply cutting pressure with the fingers. Rotate the headstock by hand and, as with the fusee engine, withdraw the cutter and reverse the work to return for the next cut.



508 18th-century fusee engine

Winding Indicator

Fusee Pinion

For a fusee watch the winding indicator, or up-and-down-work, is simply a pinion on the fusee arbor engaging a wheel carrying a hand. For a fusee turning six times in thirty hours, indicated by a hand turning through, say, 270°, then:

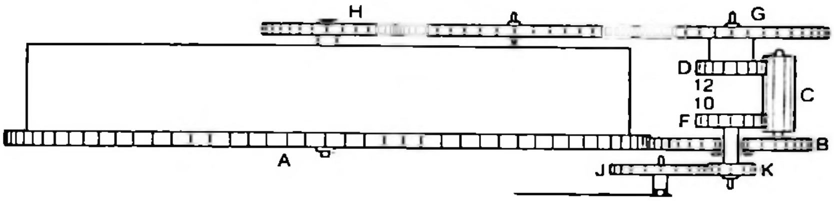
$$\frac{360^\circ \times 6}{270^\circ} = 8:1,$$

the ratio for the pinion and wheel.

Epicyclic System

With the going barrel the mechanism is more complex because the barrel is stationary during winding. It is necessary to turn the indicator in one direction with the winding wheels and in the reverse direction with the great wheel or barrel.

The system shown in Fig 509 relies upon the different numbers of teeth of two wheels of the same diameter engaged by an epicyclic pinion. The barrel *A* in unwinding turns wheel *B* to roll pinion *C* around wheels *D* and *F*. The wheel *F* has fewer teeth than *D* and so



509 Epicyclic winding indicator

gains in revolutions. The hand is turned by the arbor of the wheel *F* and, in turning, indicates the hours of running on the dial. During winding wheel *G* is turned by the barrel arbor winding wheel *H* and rotates *C* on its pivot pin to turn *F* and reverse the direction of the hand. The angle of turning of the hand will depend upon the ratios of *A* and *B* combined with *H* to *G* and *D* to *F*. The ratio of *A* to *B* will be decided by the space available for *B*.

For a barrel turning four times in thirty hours and driving *B* in the ratio of 4:1 then *B* will turn sixteen times in thirty hours. It is required to turn the hand on *J* through 270° in thirty hours. The barrel of 96 teeth turns wheel *B* during unwinding. Each turn of *B* will roll pinion *C* around the stationary wheel *D* of 12 teeth. Each revolution of *C* will advance wheel *F* of 10 teeth by the difference of 2 teeth. *F* will turn:

$$\frac{32\text{ teeth}}{10\ (F)} = 3.2\text{ turns of } F.$$

During unwinding *H* turns *G* via the intermediate wheel. *D* is fixed to *G* and must return 32 teeth of *F* via pinion *C*.

$$\frac{32}{12} = 2.66$$

$$\text{and } \frac{4\text{ turns of winding}}{2.66} = 1.5{:}1$$

which is the ratio between *H* and *G*,

$$\text{say } \frac{24}{16}$$

The 3.2 turns of *F* must be reduced to produce 270° of *J* on the dial.

$$360^\circ \times 3.2 = 1152^\circ$$

$$\frac{1152^\circ}{270^\circ} = 4.26\text{, say, } 4.25$$

$$\text{and } \frac{1152^\circ}{4.25} = 271^\circ \text{ from } \frac{34J}{8K}$$

which is near enough to the required angle. The numbers of teeth in the wheels are a matter for individual choice.

Differential Gear System

Fig 510 employs a system of differential gears. The indicator hand is carried on a wheel G driven by the shaft *F*. Running loosely on the shaft are the two wheels *D* and *B*, each with extra contrate wheel teeth engaging the wheel *E* on the axis *O* forming part of *F*.

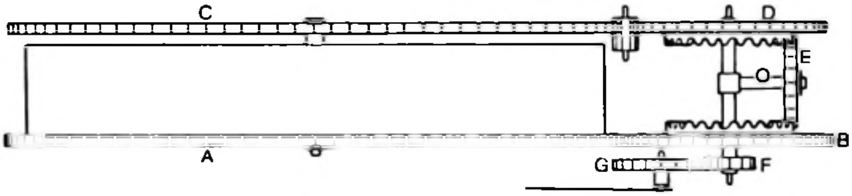
In turning C during winding, *D* will roll *E* around the contrate teeth of *B* to turn shaft *F* and move the hand. *F* will reverse its motion when *B* is turned by *A* during unwinding. The ratio $A:B$ equals the ratio $C:D$ and an intermediate wheel will be needed between one pair to reverse the motion of *F*. $\frac{A}{B} = \frac{C}{D}$ = twice the number of turns of *F*.

For barrel *A* turning four times in thirty hours and turning *B* in the ratio 3:1, shaft *F* will turn six times in thirty hours. The hand is required to turn 270° in thirty hours.

$$\frac{270^\circ}{6} = 45^\circ \text{ per turn of } F$$

$$\frac{360^\circ}{45^\circ} = 8 \text{ turns of } F \text{ to 1 turn of } G$$

This can be achieved in one pair of wheels in the space available beneath the dial.



510 Differential winding indicator

Differential Screw System

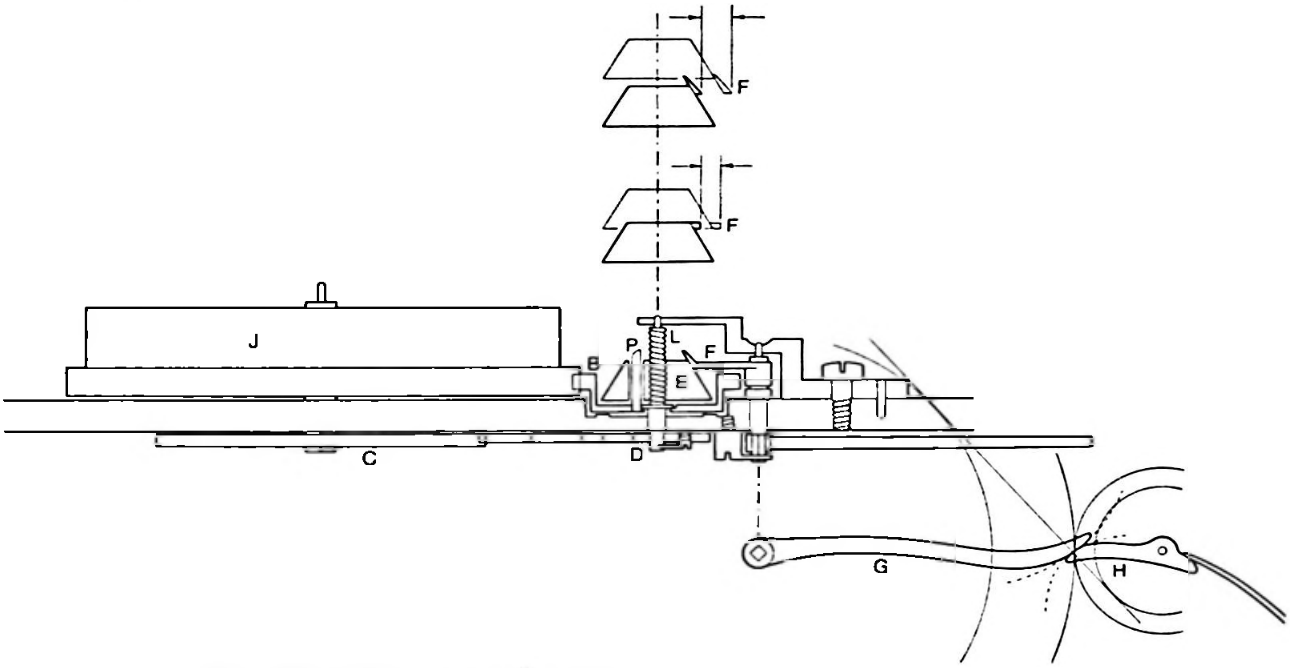
For an indicator turning through a small angle, as for example in the sector of the dial in Plate V, a differential screw mechanism can be used. This is shown in Figs **511a** and **b**, where *C* is turned while winding and turns wheel *D* squared on to the thread of shaft *L*, and as *L* turns *E* rises to push aside arm *F* which, through the linkage *GH*, turns the indicator hand.

As the barrel *J* turns in unwinding, wheel *B* is turned and, through pin *P*, screws the nut back down the stationary thread to reverse the motion of the hand. The angle of turning of arm *F* depends upon the angle of taper of the nut and the pitch of the thread for a given number of turns. Note that in Fig **511a** the acting end of the arm *F* must be extended to prevent it falling beneath the extra rise of the nut if the pitch is increased.

If the required angle for the indicator hand is 55° and the arm *G* turns 14° then:

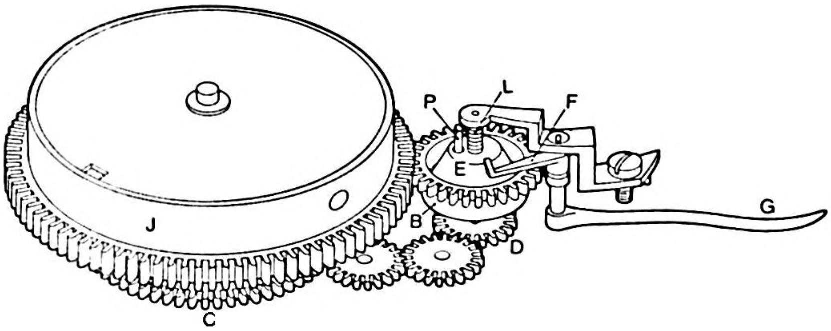
$$\frac{55^\circ}{14^\circ} = 3.57$$

and a link *H* is required to turn 3.57 times the angle turned by *G*. The hand should rise as the watch is wound, and fall during unwinding. The mechanism is used in the watches illustrated in Plates II, IV and V.



511a Differential screw winding indicator

The wheel *B* is one-third the diameter of the barrel which turns four times in thirty-two hours. Shaft *L* will need twelve turns of thread plus one spare turn at each end to prevent the nut binding. The diameter is 0.9 mm of which 1.68 mm is needed for twelve turns.

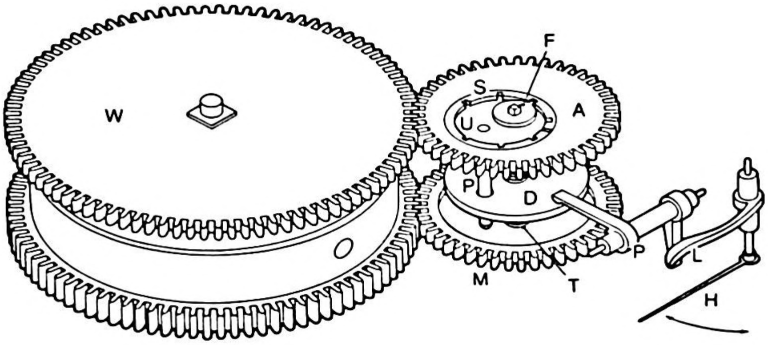


511b Differential screw winding indicator

Combined Winding Indicator and Stop Work

The arrangement shown in Fig **512** combines stop work with a winding indicator. By this means the height of the mainspring can be increased by the thickness of the stop work. The wheel *M* is fixed to a threaded arbor and turned by the barrel during unwinding.

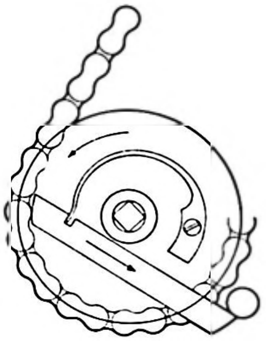
The stop finger *F* is squared on to the arbor. Each turn of *F* will advance the hoop *S* until the finger locks on to the unslotted sector *U*. At the same time disc *D* is screwed down the thread to indicate the mainspring condition via link *L* and hand *H*. During winding by wheel *W*, wheel *A* turns around the stop finger to reverse the hoop. When the finger meets the unslotted sector the spring is fully wound. As *A* turns, pin *P* screws disc *D* down the thread to reverse the motion of the hand *H*.



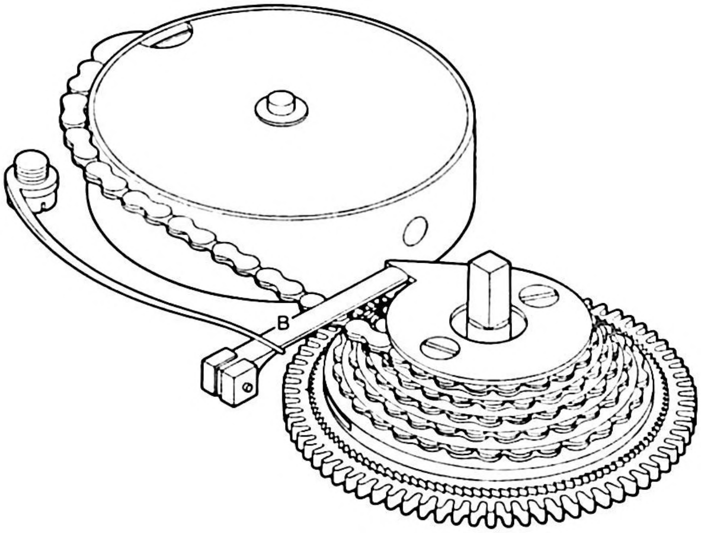
512 Combined winding indicator and stop work

Stop Work

For the fusee a simple pivoted stop works well. It is shown in Fig 513 in which the chain, wound on to the fusee, has raised the bolt *B* into the path of the fusee steel stop finger to prevent further rotation. For a reversed fusee the finger must catch a hook and lock with *B* in tension. Some fusees have a sliding finger, as shown in Fig 514, which is pushed through the fusee slot, beneath the cap, to catch a post screwed into the plate.



514 Fusee stop work



513 Fusee stop work

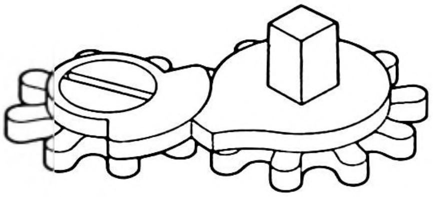
Breguet preferred his own stop work, shown in Fig **515**, both for the fusee and going barrel. It is very strong and the two components are geared together in the ratio of 4:5 so that they lock tangentially. Its disadvantage is the height of the double layer.

The Geneva stop work succeeded all others, once it was accepted that its apparent fault of not locking tangentially was not harmful. It is shown in Fig **516**. The finger piece is squared on to the barrel arbor. The star wheel is fitted to the barrel. The three positions of its action are illustrated at *B*, *C* and *D* in Fig **517** and it can be seen from the angle of the dotted line in *A*, locked, that the locking can cause considerable pressure on the star-wheel screw. The star wheel must be seated on a pipe formed in the barrel sink, as in Fig **518**, so that the pressure does not bear upon the screw thread.

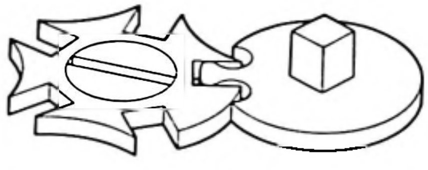
Note that the fit at position *D* of Fig **517** should be very close if jamming is to be avoided between shoulder and hollow as happens at position *C*. The lead from the finger at *B* after the centre line is only 24° and the shoulder must complete the half-angle of 36° of the star wheel to the locked position.

For very thin watches, the height of the barrel can be reduced by fitting the stop work to wheels separately driven to one side of the barrel. Fig **512** shows the arrangement also adapted to operate the winding indicator. The upper wheel *A* is turned by the winding wheel *W* until stop finger *F* butts upon the unnotched sector *U* of stop ring *S*. At the same time pin *P*, fixed in wheel *A*, will turn disc *D* on the thread *T* to raise arm *P* and indicate the spring fully wound with hand *H*.

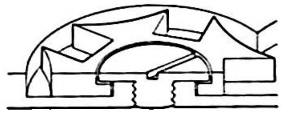
While unwinding, wheel *M* is turned by the barrel, and thread *T*, fixed at its centre and carrying the stop finger *F*, turns with it. This lowers *D* to indicate the spring run down and returns *S* to the locked-down position at *U*.



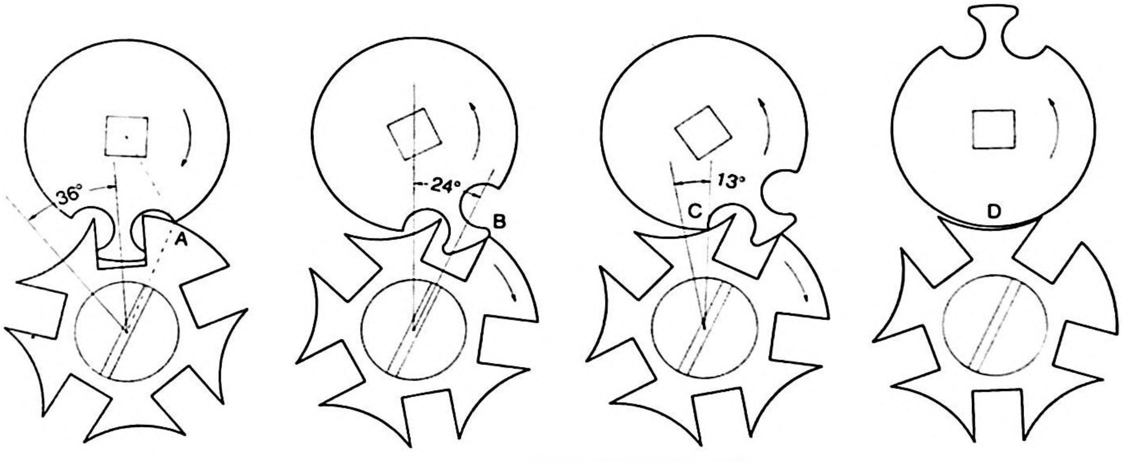
515 Stop work by Breguet



516 Geneva stop work



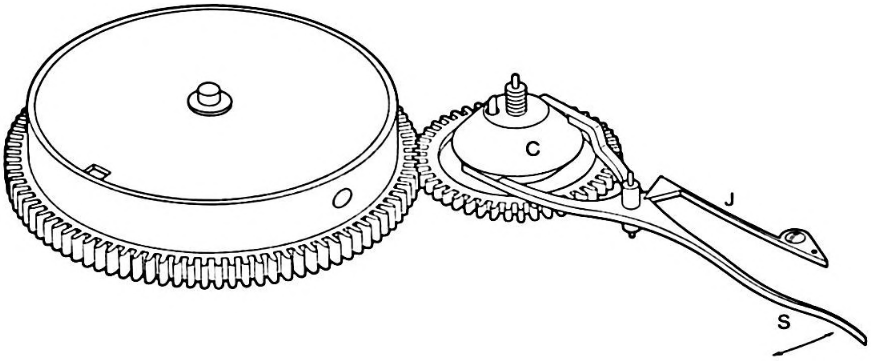
518 Geneva stop work star-wheel screw



517 Action of Geneva stop work

Balance Stop Mechanism

If it is required to stop the balance vibrating before the spring is completely run down the method shown in Fig **519** can be used for the winding indicator. Stop spring *S* is forked to embrace the winding indicator cone *C* which, in rising, pivots *S* to release the balance. As the cone falls during unwinding, *S* turns back to lock the balance. The underside of the cone is bevelled at the edge to catch the lower limb of *S*. The spring *J* causes *S* to jump into and out of engagement with the balance to ensure a positive action.



519 Balance stop mechanism

Winding

The watches illustrated in this book are all wound with a key. The reason for this is that keyless, or stem-wound, watches are generally neat in appearance but difficult to wind. If they are easy to wind they are often clumsy in appearance. When the winding button is large enough to grip easily it begins to dominate the case and influence the style of the watch. It is for this reason that after about 1860, with the advent of the quantity-produced watch for people who seemed to care little for aesthetics and were apparently too feeble to use a key, the appearance of the watch degenerated into a tasteless and keyless, dull uniformity.

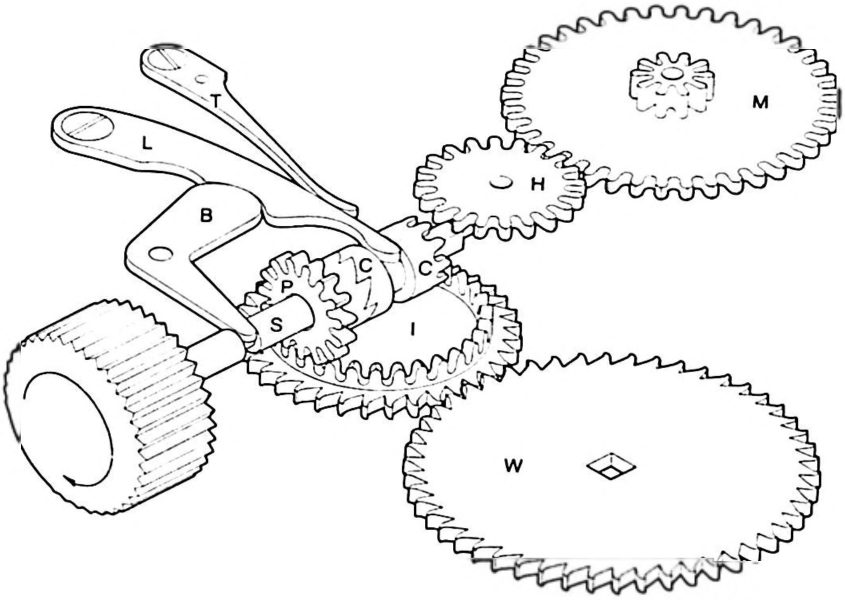
The key-wound watch and the automatically wound watch can be designed wholly on aesthetic grounds without regard for the inclusion of a means of maintenance. A study of watches made since the early seventeenth century shows that the pendant always had style and elegance which echoed the beauty of the watch.

The form of the keyless pendant is always decided by the winding button, but the increase in mass of metal draws the eye away from the dial. At the turn of the nineteenth century, Willis and Hood, who made dials and hands respectively, were obviously aware of the dominance of the keyless pendant when they introduced heavier numerals and hands to emphasize the dial. By this means the eye is attracted to the dial, which should be the most obvious aspect of a timekeeper. But it is far better to make the dial more prominent by reducing surrounding distractions so that the watch will have greater elegance of functional purpose.

Keyless Design

The system of keyless winding and handsetting was introduced by Breguet in about 1820. He did not favour it and made only a few examples, using a separate hand-setting button set into the winding button.

The system shown in Fig 520 is most commonly used for both pocket and wrist watches. The clutch *C* is a sliding fit on winding stem *S* and engages winding pinion *P* in which *S* is free to rotate. When *S* is turned in the direction of the arrow, clutch *C* turns pinion *P* to turn wheel *I* which engages the winding wheel *W* to wind the spring. When *S* is turned in the opposite direction spring *T* yields to allow clutch *C* to ride over the ratchet teeth of *P*. To set the hands, *S* is pulled to swing bolt *B* on to the incline of *L* to lower *C* into engagement with the handsetting wheel *H*, to turn the minute wheel *M*.



520 Keyless winding mechanism

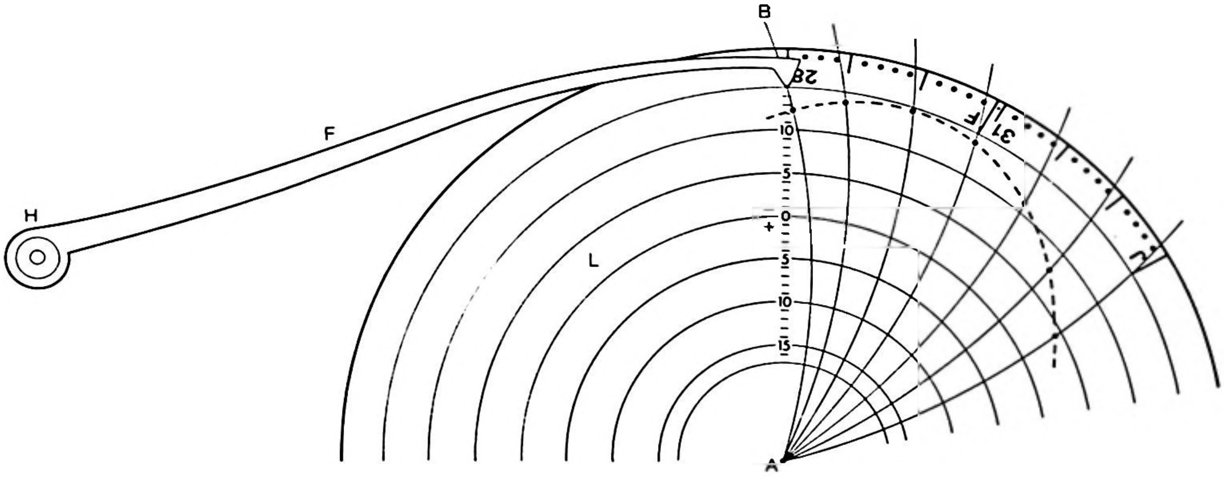
Equation of Time

The Equation of Time for the day is the difference between true solar time and mean solar time. It arises from the unequal daily passage of the earth in its elliptical path around the sun. It can be shown on the dial of a watch by a suitably shaped cam and follower.

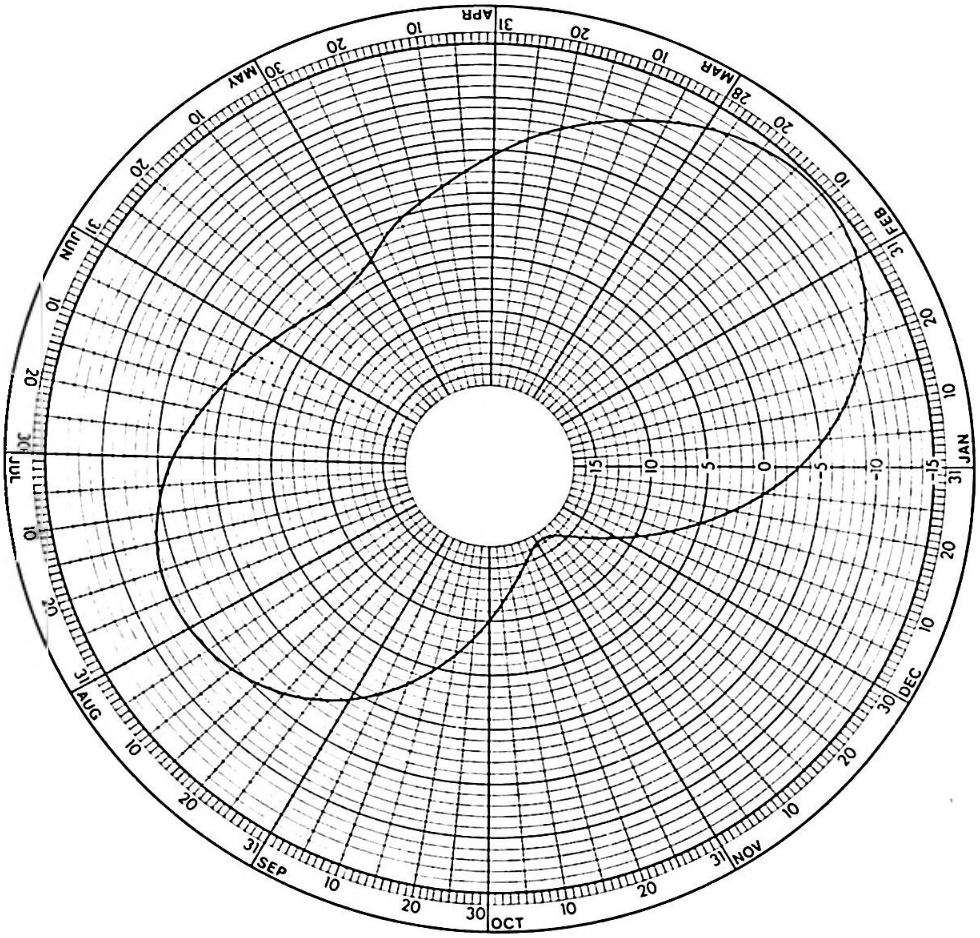
Plotting the Cam

The shape can be produced by the method shown in Fig 521. The outer circle is divided into days of the month. On a large drawing every day can be marked. If the cam is to be marked out to actual size on the metal the days will be more easily marked in groups of ten with subdivisions of two.

Note that the radial divisions are curves struck from the centre of motion of the follower *F*. The concentric circle *L* is zero. Circles within this show the sun gaining. Circles outside this show the sun losing. Each subdivision represents one minute. The greatest gain is less than seventeen minutes and the greatest loss less than fifteen minutes.


B
F
H
L
A
28
F
31
10
5
0
+
5
10
15

521 Plotting an equation cam



522 Equation chart suitable for cam computation

Plot the cam against the radial minutes and angular days, marking with a point each intersection, and finally join smoothly with a continuous line. The shape of the cam will depend upon the proportional radius of the zero circle and the position and length of the cam follower arm. The method of plotting remains the same and the figures can be taken from the table shown in Fig **522**.

When a pantograph milling machine is available the cam can be cut to scale using the drawing. To make a master cam, paste the drawing to a sheet of aluminium and cut out with shears.

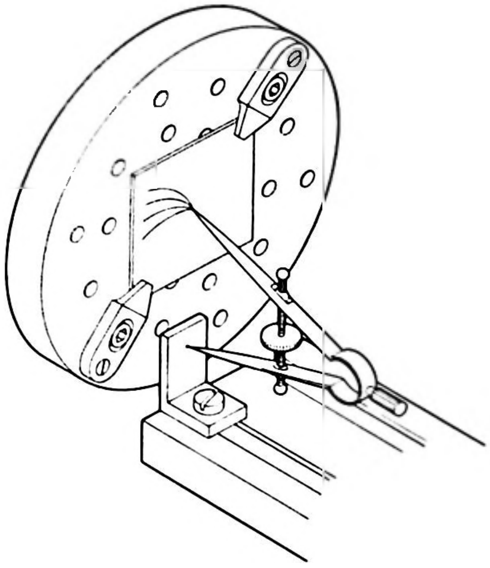
Making the Cam

If the cam is to be marked out to size prepare a piece of steel and smooth on one side and colour blue in the flame. Drill a hole at the centre and scribe circles of diameter equal to the maximum, minimum and zero equation radii of the cam.

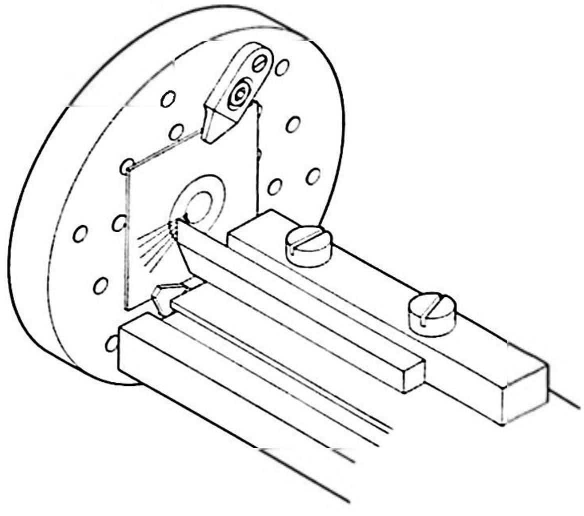
At the largest convenient radius scribe the circle for the months and divide these into ten-day periods, as in Fig **521**. Pivot the steel on a pin in a brass plate and drill a small hole *H* in the plate at the radius of the cam follower *F*. With dividers mark off from hole *H* the curved radii, *AB*, for each month.

Scribe the concentric circles for the minutes and plot the cam against the table, as shown in Fig **522**. Make the plotting points with a small, sharp chamfer to leave a bright spot on the blue surface of the steel. On a very small cam it will be easier to mark the circles at two-minute radii. This, combined with the ten-day periods of the month, will require the final position of the plotting mark to be estimated to the nearest circle and radial.

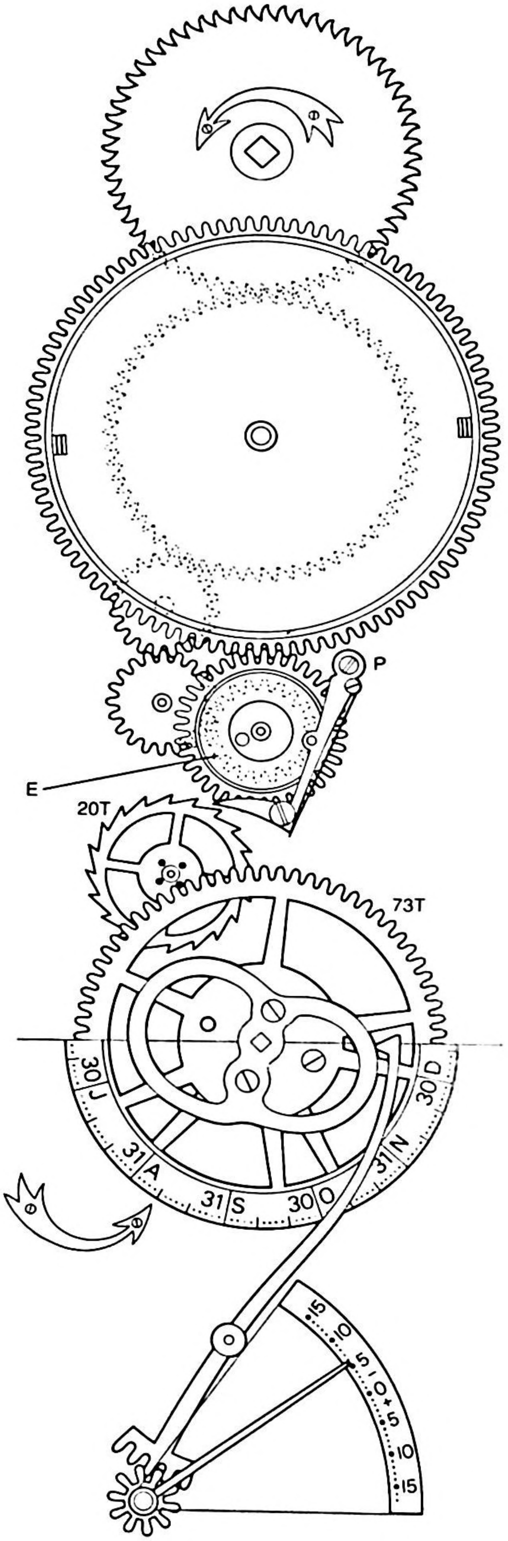
The cam can be precisely marked out in the lathe if a 365° circle of division is available. Clamp the steel to the face plate. Fix a bracket to the slide rest, as in Fig **523**, at the radius of the follower, and with the dividers located in the bracket and set to the centre height of the



523 Marking out the months in the lathe



524 Marking out the minutes in the lathe


P
E
20T
73T
30 J
31 A
31 S
30 O
31 N
30 D
15
10
5
–
0
+
5
10
15

525 Simple system for the Equation of Time

hole scribe the radials for the months. In this way the two-day periods can be clearly marked with accuracy. For the concentric circles select maximum and minimum diameters which can be conveniently divided by the pitch of the slide rest screw.

Fix a bracket to the slide rest, as shown in Fig 524, and hold a sharp cutter against the bracket between finger and thumb. Set the point of the cutter at the centre of the hole. With the slide-rest screw move to the position of the minimum radius of the cam. Gently press the point of the cutter to the next minute radius using the screw thimble as an index. Scribe the circle and repeat the process to complete the circles. In this way every minute circle can be clearly and accurately marked out.

Cut out the cam and fit to the watch, complete with follower and indicator hand. Check round the cam, noting on paper the date and extent of any errors. Where errors occur mark the cam at the point of contact of the follower. Correct any errors by filing and then finish each correction with a smooth stone. Finally, harden and finish as required.

Equation Date

The simplest form of date indication is a dial divided at the edge with the months subdivided into days. The dial moves one division each day and, with the exception only of leap year, the variable lengths of the months are shown correctly.

The watch illustrated in Plate II uses this method to turn the equation cam. The cam is fitted to a wheel of 73 teeth. A wheel of 20 teeth is turned 1 tooth each day during winding and carries a pinion of 4 pins to engage the cam wheel. The arrangement is shown in Fig 525. The pawl P is rocked by the cone E of the winding indicator as it rises during winding, as in Fig 511. For leap year the calendar wheel must be turned back to 28 on the 29th day. The ratio for the wheels is $\frac{73}{4} \times 20 = 365$ windings for one turn of the cam wheel.

10

MOVEMENT DESIGN

Historical and General

The earliest watches were full plate. All the components were between two plates, with the exception of the balance which was supported in a cock above the back plate. This arrangement simplified construction because the back was fitted over the ends of the spacing pillars and secured by pins. No steady pins or screws were needed. This arrangement persisted for Continental, commercial-grade watches until the early nineteenth century. Some English makers continued to use it until the end of the first quarter of the twentieth century.

After 1800, Continental watches were made increasingly to Lepine's calliper, in which all the components are separately secured to a single plate by cocks secured and located with screws and steady pins. The balance wheel also is supported by a cock screwed to the plate so that it is no longer the highest component in the watch. Obviously the movement could be made thinner and as a result encouraged the manufacture of thin watches.

The English makers reduced the thickness of their movements by cutting away part of the back plate to make room for the balance supported in a cock screwed to the front plate. When the fourth wheel was pivoted in the back plate the calliper was called a three-quarter plate; when pivoted in a separate cock the calliper was called a half plate.

The Lepine calliper has greater appeal than the plated movement because all of the mechanism can be seen. Also the multiplicity of cocks and screws seems to indicate fastidious application and love of craftsmanship for its own sake. In the nineteenth century the Swiss makers were particularly concerned with the appearance of their watch movements. It is usually the case that when a watchmaker cannot make a technical advance he will divert attention by decorating his work. The Lepine calliper lends itself admirably to embellishment. But good practice dies hard and although the Swiss now lead technically, and micro-precision engineering has taken the place of watchmaking, the best Swiss makers continue to apply a jewel-like finish to their products.

The English makers also worked to a very high standard but did not make any obvious effort to intrigue the customer with a display of polished wheels and sparkling components. There would be no point in doing so. English hand-finished watches were expensive and bought only by gentlemen. They, on the whole, were not interested in wheels or polish which were merely manifestations of trade, something which no gentleman would want to be thought to recognize.

By the end of the nineteenth century English supremacy in watchmaking, achieved during a hundred years of painstaking development of English inventions, had begun to slip away. The Swiss had learned to utilize these inventions in a different way in order to produce cheaper watches with equally good performance.

The English formula for a high-grade watch included a fusee and chain, a heavy balance wheel and a helical balance spring with preferably a multitude of terminal curves and no regulator. Since the days of Arnold the English had been taught that regulators were for inferior watches. The Swiss preferred a movement with going barrel, a light balance with a spiral spring with Breguet terminal curve and a regulator. These were developed to such a high degree that by the 1920s their performance exceeded the best rates of the English watches.

It would be a simple matter to copy the design and proportions of the Swiss watch. But the aspiring watchmaker should endeavour to give some individual personality to his work. This is especially important because a high-grade, factory-made watch can be bought for a small fraction of the cost of a hand-made watch. Buyers of hand-made articles are willing to pay for the high cost of production only if the article is necessary to their comfort or offers a new aspect to a subject of interest.

It is not an easy thing to design a watch that has novelty as well as improved performance. Both aspects are important because, while the watch may reflect the individuality of its maker, it will be incomplete if it cannot perform its basic function as well as any before it. If it can do better it will add to the science of the mechanical, portable timekeeper and give both maker and buyer greater satisfaction.

Not every maker will need or want to sell his work. The professional will, and as a consequence he will have the sometimes unwelcome and often biased views of his customer on the performance of his watch. But he will be the more fortunate for he will have the benefit of knowing where to make improvements that otherwise might not occur to him. He should, however, beware of idiosyncrasies and make allowances for errors of judgement that are sometimes included in the buyer's opinions.

It is inevitable that each succeeding watch made to the same design will be a little different. There is always something new that can be tried and which may effect an improvement. The long-term results cannot always be predicted and provision should be made for the possible necessity of reverting to a proven method.

Planning the Movement

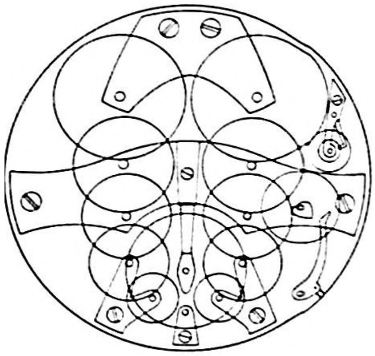
When laying out the plan of the movement do not forget that the watch must have hands. They should appear on the dial so that they are easy to read and at the same time present a pleasing arrangement. When the space is limited the most suitable initial arrangement of the wheelwork can be found by using discs or discarded wheels of appropriate size. These can be laid on the plate and moved about to find the best positions and diameters. Small components to function with the wheels can be marked in with a hard pencil. In this way the basic layout can be arranged with ease in preparation for ascertaining the detail dimensions at the drawing board. When satisfied with the arrangement for the train and escapement be sure there is adequate space left clear for screws and steady pins.

Movement Template

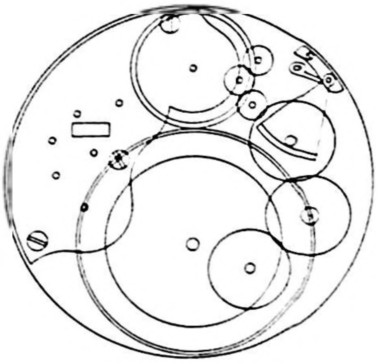
Prepare a brass disc of the diameter of the movement and lightly scribe the circles and lines for the wheels, pinions and bridges as a check that the final plan is satisfactory. The position of the wheels carrying the hands will be the cardinal points in the design, and holes marking their positions can be drilled 0.5 mm diameter and following depths scribed from them. When the wheels and pinions are made and their exact depths found, the plate can be firmly scribed and holes drilled for the positions of the remaining wheels, as in Fig **526a**. On the reverse mark out the positions of the components under the dial, and the circles, sectors and signature zones that will appear on the dial, as in Fig **526b**. Figs **526a** and **b** show plates for watches of the type illustrated in Plate V. If more than one watch is required the plate can be used as a drilling template for the wheel depths and screw holes. Keep a record of the wheel and pinion diameters and numbers for future reference.

It is not always possible to know exactly what dimension a component should have and this must be discovered by trial. Its shape for its function will be known, as will also the position of the acting surfaces. The remainder must be arrived at by experience. Always make a sketch of the component and note the dimensions and any future modifications that can be included. It may be some years before a similar piece is required and the information will simplify the work.

When it is necessary to set up a machine to produce a component make several extra pieces for possible use. The time taken to machine a component is often a fraction of the time needed to set up the machine. This is especially so with pinions which are tedious and costly to make individually. Often, a stock pinion can be used by making a small alteration to the design of its wheel without in any way adversely affecting the appearance of the movement.



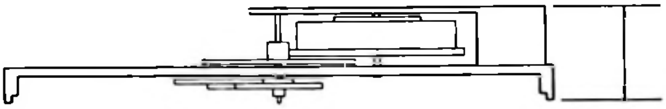
526a Movement template



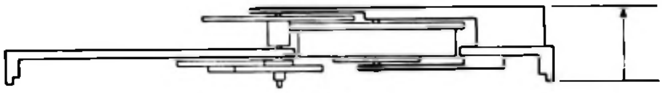
526b Movement template under-dial side

Elevation

During the course of planning the layout of the components, consideration should also be given to their elevation. Unnecessary overlaying of components will make the watch thicker than it need be. An example of this is shown in Figs **527a** and **b** in which the centre wheel is below the barrel in a and above in **b**. For the same component dimensions, it can be seen that the arrangement in **b** produces a thinner watch. The thickness of the overlapping components and their necessary running clearances will obviously influence the final height of the movement. These must be kept to the practical minimum consistent with the required strength and reliability.



527a Centre wheel below barrel



527b Centre wheel above barrel

Detail Design of a Tourbillon Movement

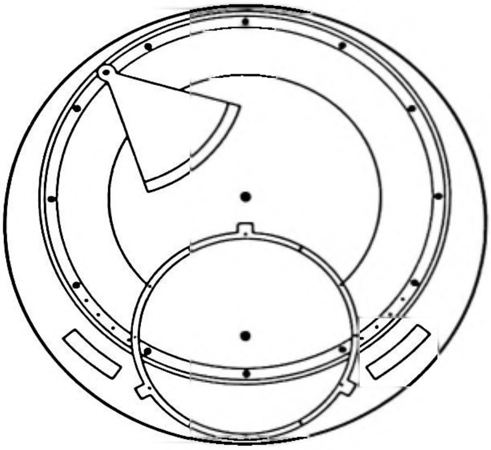
The watch illustrated in Plate III is some 62 mm in diameter with a movement of 58 mm diameter. It has two barrels wound simultaneously and a *tourbillon* carriage with spring detent escapement. With two barrels the extra power required to overcome the inertia of the carriage can be obtained without increasing spring stress.

Increased power from one spring would also apply increased pressure to the centre pinion leaves and pivots. With two springs the pressure on the leaves will actually be reduced because each acts upon a different leaf and the springs will be thinner than a single spring. The force from the barrel teeth is applied at opposite sides of the pinion and so its pivots are relieved of the pressure with consequent reduction in friction.

Dial Layout

The general arrangement of the barrels and carriage allows the maximum diameters for each. The precise positions are fixed by reference to the dial which must be marked out with great accuracy on a brass plate. It will later be used as a drilling template for the movement and dial.

The final positions are shown in Fig **528** with the diameters for the minutes and seconds adjusted to fill the available space but without obscuring any divisions. If an up and down sector is to be used it must be marked and the centre for its pivot located. With the centre, seconds and sector holes drilled 0.5 mm diameter the positions for these components can be found.



528 Dial template

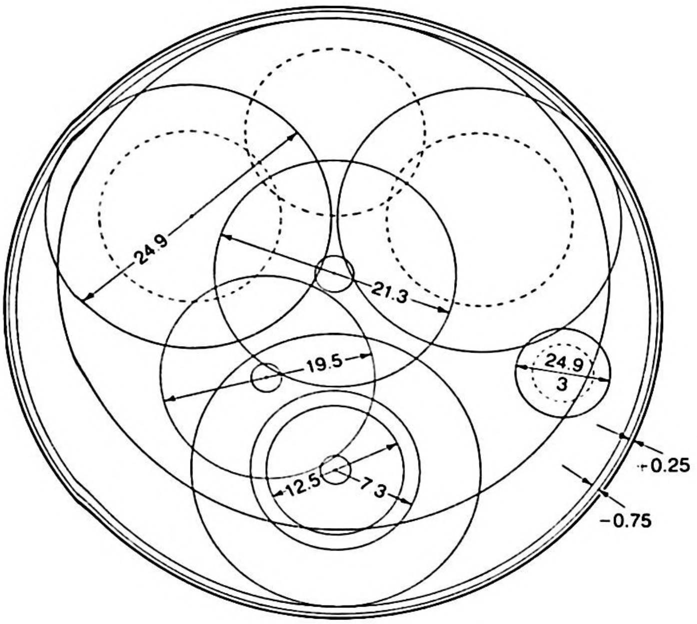
Pitching the Wheels

On paper draw a circle four times actual size and put in a centre line. Mark the positions for the centre, seconds and sector holes taken from the plate. Check their location by drawing in the circles for the minutes and the seconds.

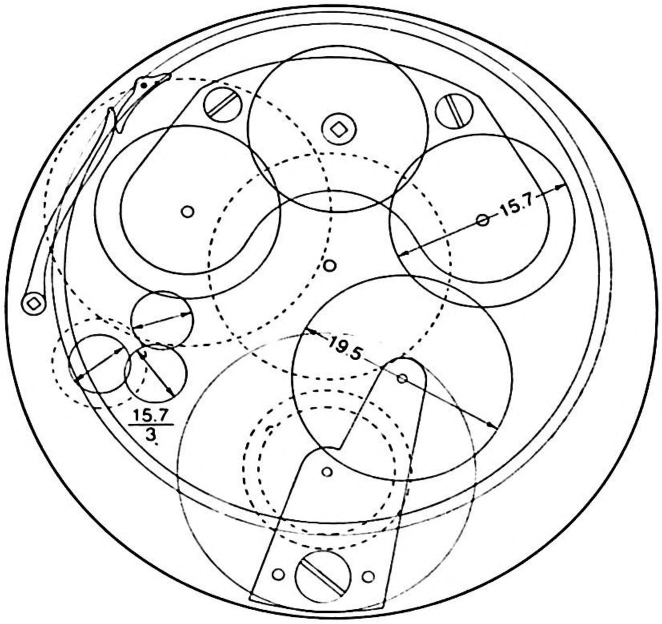
Prepare a list of suitable ratios and by inspection mark on the drawing the most convenient pitch diameters for the wheels and pinions. In Fig **529** a circle of 0.25 mm greater radius than the dial indicates the full diameter of the movement, and an inner circle of 0.75 mm smaller radius than the dial indicates the inner edge of the case band. The area inside this inner circle is available for the wheels. The barrel to centre ratio is 8:1 and this must be fitted into one side of the centre line. The teeth may touch the case circle but not the centre line and allowance must be made for the addendum of the teeth. The diameter for this watch is 24.9 mm full diameter measured from the drawing. The second barrel can be drawn in at the same diameter.

The position of the fourth wheel is fixed by the drilling for the seconds. This will in fact be the pivot for the carriage, and the fourth wheel will be fixed to the plate concentrically beneath. The diameter of the centre wheel is influenced by the design of the carriage which has in this instance fixed the diameter of the fourth wheel at a maximum 12.5 mm full diameter. This circle can be drawn centred at the mark for the carriage pivot. The escape-wheel potence jewel setting is 1.5 mm diameter and its outer edge is 7.3 mm radius. Allowing 0.2 mm clearance between the centre wheel and the jewel setting will fix the edge of the centre wheel at a radius of 7.5 mm from the centre of the carriage. Draw this circle, which will be found to be 21.3 mm full diameter. The chosen ratio between the centre wheel and third pinion is 8:1 and so the diameter of the pinion can now be found. The ratio between centre and fourth wheels must be 60:1 and so a ratio of 7.5:1 is required. A full diameter of 19.5 mm will allow sufficient clearance between the escape-wheel potence and the third-wheel cock.

If, when the wheels and pinions are made, their final diameters differ slightly from the drawing this will not matter. The differences will be resolved in the final positions of the barrels and third wheel which will, in any case, need to be pitched with the depth tool. The centre-wheel to seconds-pivot distance can be maintained by a small adjustment to the third-wheel position.



529 Wheel plan for a *tourbillon* watch



530 Under-dial wheel plan for a *tourbillon* watch

Winding Wheels

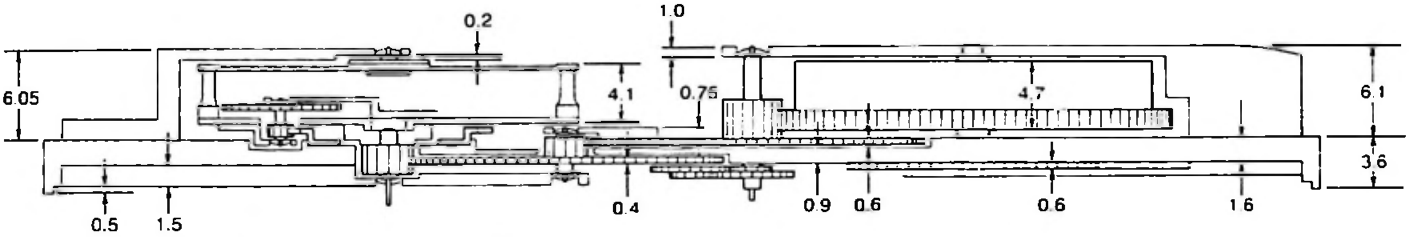
The diameter of the winding wheels can now be found and included in a drawing of the dial side of the plate, as in Fig 530. Their diameter of 15.7 mm is determined by the position of the winding-square bearing in the barrel bridge. Note, for the full diameter, that these wheels have ratchet teeth without curved addendum, but the form of winding teeth is a matter of preference.

If up and down work is to be fitted the position for the barrel wheel can be determined from the barrel diameter. The ratio will need to be 3:1 because space is limited. It is beneficial in this example because the mechanism will be brought closer to the pivot point in the dial to reduce the length of the linkage.

Elevations

Inevitably a *tourbillon* watch, with one-minute period of rotation, will be thicker than a conventional watch. This is because the circles for the carriage, third wheel and centre wheels will overlap. The centre wheel must be under the carriage and as a result the barrel will be above the centre wheel. The effect of this arrangement is shown in Fig 527a where the space beneath the barrel cannot be used. The carriage height above the centre wheel is determined by the upper, third-wheel cock which must allow sufficient clearance for the centre wheel to engage the pinion securely. The third wheel can be recessed into the plate and supported in a potence within the depth of the dial-side recess.

This potence can also carry the lower carriage pivot jewel hole. The winding wheels with their cover plate will also fit into the dial-side recess and leave adequate room for the motion work. The elevation of the train is shown in Fig **531** as a guide to the dimensions and clearances suitable for a movement of 58 mm diameter.



hollow centre pivots for handsetting arbor	1.4 mm diameter
3rd wheel pivots	0.3 mm diameter
carriage pivots	0.3 mm diameter
escape wheel pivots	0.14 mm diameter
balance pivots	0.10 mm diameter

531 Elevation dimensions for a *tourbillon* watch

Planning the Carriage

The space available for the carriage can be found from the drawing of the plan of the movement in Fig **529**. It is centred on the seconds pivot jewel hole. Draw the circle for the carriage to allow clearance at the inner edge of the case. The diameter available is 25.5 mm. The height can be found in Fig **531**. This allows 4.2 mm to be available if the carriage supporting bridge is not to exceed the height of the barrel bridge.

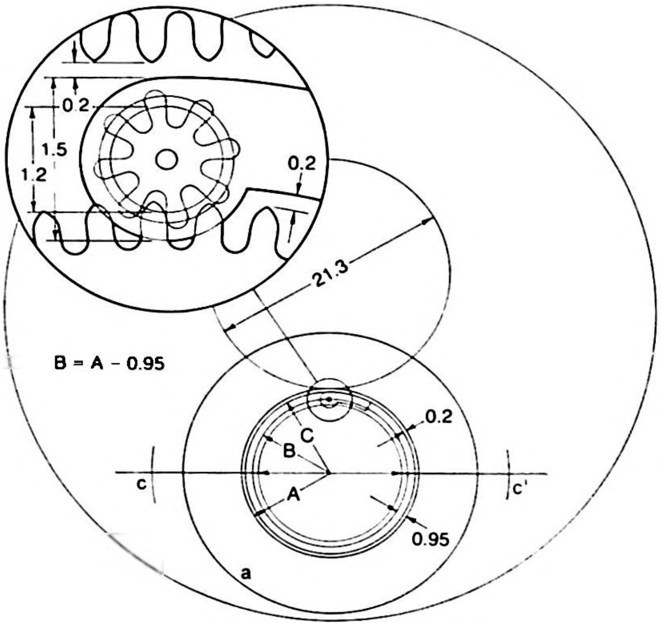
The design of the carriage is inseparable from the design of the movement. The position of the escape wheel in the carriage is fixed by the radial space available at the outer edge of the centre wheel. More room would be available if the escape potence were allowed to rotate above the centre wheel. This is the conventional arrangement with the centre wheel at the centre of the movement. Moving the centre wheel to engage two barrels has, for a little extra care in design, allowed sufficient room to lower the carriage by the thickness of the centre wheel plus the necessary running clearance.

Allowing 12.5 mm diameter for the fixed fourth wheel has set the diameter of the centre wheel at a maximum 21.3 mm full diameter. Measure the distance from the edge of the centre wheel to the carriage pivot. From the pivot centre scribe a circle with radius of the measured distance less 0.95 mm. The 0.95 mm represents half the diameter of the potence jewel setting plus 0.2 mm clearance between the setting and the centre wheel, as in Fig **532**, radius *B*. This is the centre distance for the escape pinion and fixed fourth wheel. The diameters of the wheel and pinion can be found from this measurement. Draw in the full diameter of the fixed fourth wheel. Draw the outline of the foot of the escape-wheel potence. Note that this needs clearance at the edge of the fixed wheel.

Radius *B* is also the centre distance of the escape wheel to balance. The escapement is a matter of personal preference. (Designs for escapements are found under the appropriate headings.) Once the overall dimensions of the carriage and its centre are known the remainder of the dimensions are a matter for individual preference. The dimensions and proportions of the various components illustrated may serve as a guide to the detail requirements of a strong but lightly constructed carriage.

Carriage Support

The support for the carriage may be a bridge or a cock. Scribe the circle *a*, as shown in Fig 532, for the diameter of the carriage on the plate. The fixing for the support will be outside this circle. For a bridge draw a line across the circle and mark the positions for the pillars, *c* and *c*'. A cock may be located in any convenient position.



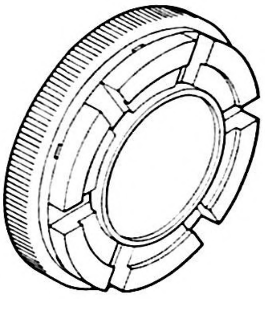
532 Planning the carriage space

Making the Frame

Preparing the Plate

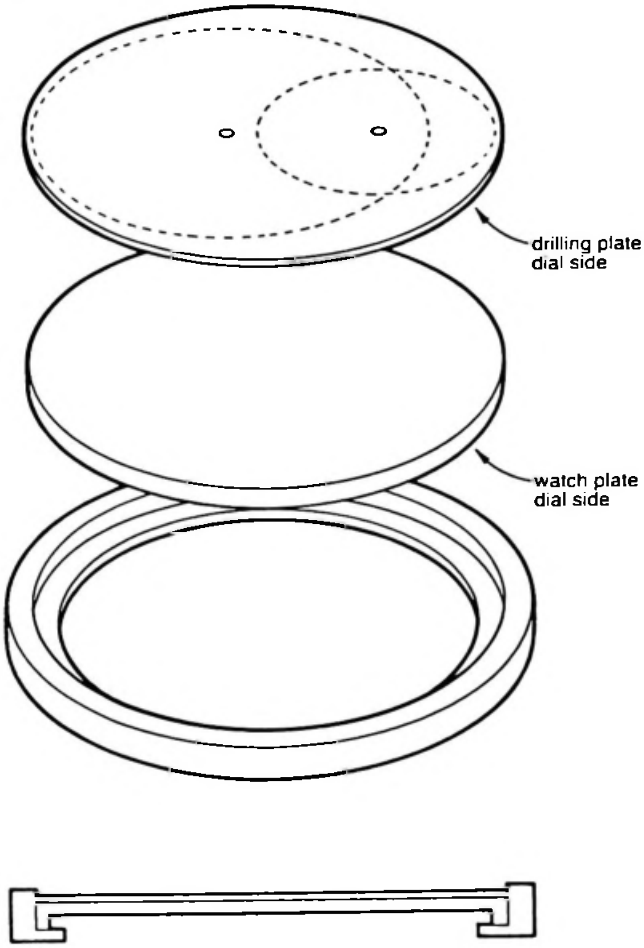
Turn a stress-relieved brass disc to the diameter and thickness required for the watch plate. The *tourbillon* illustrated in Plate IV has a plate 58 mm diameter and 3.6 mm thick. The dial side is recessed 2 mm to receive the motion work and winding wheels, as shown in Fig 531.

Start with a plate of 5 mm thickness and any convenient diameter. Turn the face clean and reduce the visible diameter to 58 mm and to a depth of 4 mm. Remove from the chuck and true the jaws to receive 58 mm diameter. Brush jaws and plate clean of dust and swarf. Grip the disc by the turned edge and clean away the unwanted metal leaving the disc 3.6 mm in thickness. Finally recess the surface to a depth of 2 mm, as in Fig 533.



533 Preparing the plate in the lathe

Turn a ring of brass to accept the plate and the drilling disc. Lay the disc above the plate within the ring and drill through the holes for the centre arbor and seconds pivot. The holes will be more certainly located if the disc is in contact with the flat surface of the watch plate. To avoid any error the dial side of the disc must be face-down on the watch plate, as in Fig 534, so that any later holes will be drilled on their correct side of the centre line. Stone both sides of the plate smooth with water-of-Ayre stone applied under running water.

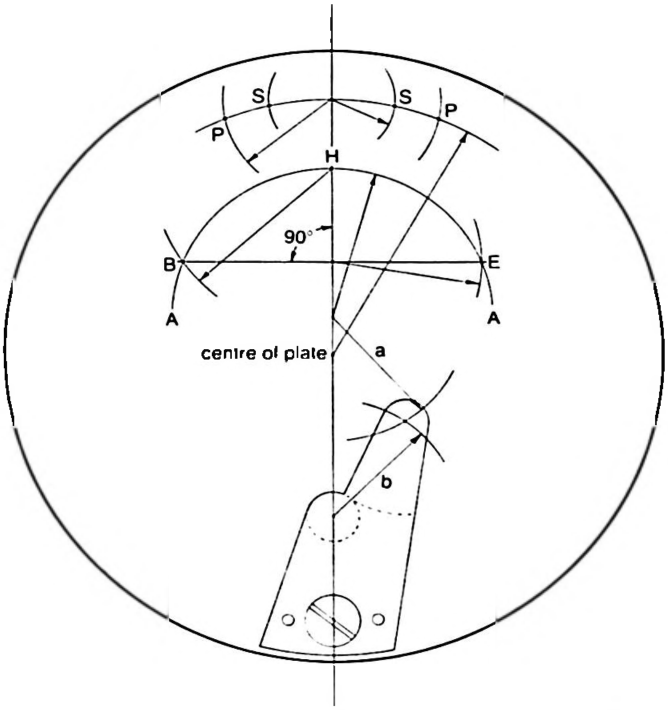


534 Drilling the plate holes through the dial template

Scribe a light line on both sides to bisect the drilled holes across the diameter of the plate, as in Fig 535. With a compass or ruler find the centre of the plate on the line and make a very small centre with a sharp point. This will be useful for scribing concentric radii to locate screws and steady pins.

Planting the Barrels

With the depthing tool find the centre distance for the barrel to centre pinion. Scribe the arc *A*, as shown in Fig 535, from the



535 Scribing symmetrical radii for screws and steady pins

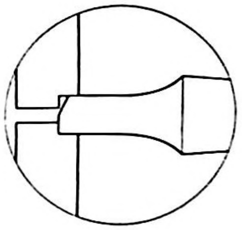
centre-wheel hole equally either side of the centre line. Set the compass to the full radius of the barrel plus an extra 0.5 mm. At this distance and at right angles to the centre line make a mark *E* for the barrel position on arc *A*. Set the compass to the distance *EH* on arc *A* and scribe the intersecting arcs *E* and *B* for the barrel positions. These lines should be lightly scribed if they are to be erased later. It is better to make one a little deeper to help to locate the exact centre of the crossing.

Find the centre by drawing a sharp point along the shallower line until the point clicks into the deeper line. Raise the point to vertical and press lightly down. Examine the mark most carefully to be sure it is correctly placed. Deepen the mark with a chamfer and drill holes 0.6 mm diameter.

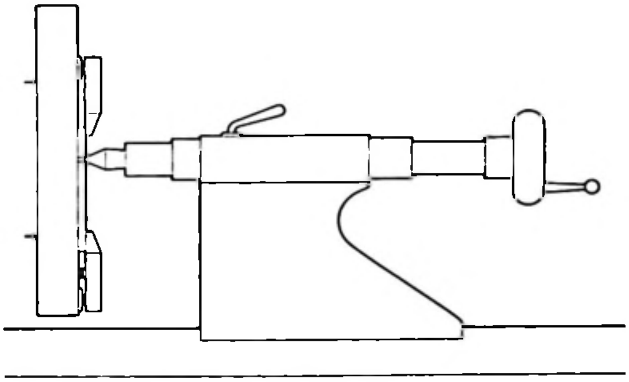
Making the Barrel Bridge

Prepare a piece of brass uniformly 6.4 mm thick and sufficiently large to grip under the clamps of the mandrel plate. A disc 56 mm diameter would be ideal and the outer edge would then be the finished edge of the bridge.

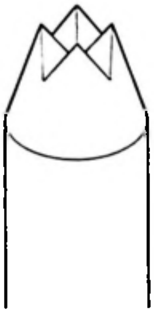
Mark the position for the screw holes in the watch plate at a suitable radius struck from the centre of the plate. As shown in Fig 535, cross the arc with further arc *S* struck from the centre line and drill the screw holes. Clamp the bridge plate concentrically to the watch plate. Its position can be found closely enough with a ruler at the edge. Drill through the screw holes into the bridge using the same size drill. Open the holes in the bridge to accept the screw threads. Counterbore to receive the heads by locating the hole with the tailstock centre, as in Fig 536. Slowly rotate the mandrel to check the truth of the hole. Tap true if necessary with a fibre or wooden hammer. Cut the sinks to the required depth with a half-round cutter in the tailstock, as shown in Fig 536a. Remove all sharp edges from both plates with a chamfering cutter. Thread the plate holes and secure the bridge plate tightly to the watch plate with the screws. As shown in Fig 535, mark off the steady pin holes, *P*, with the compass. Drill 0.95 mm through the plate to a depth of 2 mm into the bridge plate.



536a Screw-head sinking cutter



536 Centring with the tailstock in the toolmaker's lathe

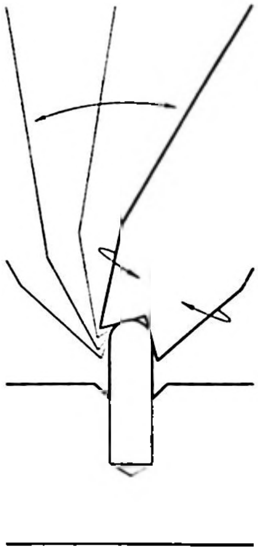


537 End-finishing tool for pins

Clean the edges of the holes in both plates with the chamfering cutter. File 1 mm brass wire to fit tightly into the barrel bridge holes with a light pressure. The wire should be well burnished and without taper when offered to the hole. Tip the burnisher over the end of the wire to remove any burr and help it start in the hole. Push the end into the hole with a slight twist. It should enter to a depth of about 0.75 mm and remain firmly in the hole. Cut through with sharp end cutters leaving the pin some 3 mm long. Tap fully home and with a file reduce to 1.6 mm length. Finish the end with a rounding cutter, as in Fig 537, by gyrating and rotating in the fingers, as in Fig 538. Note the pin set in a deep chamfer to avoid distortion of the surface of the metal.

Fit the pin to the plate hole by easing with a smooth broach lubricated with thin oil. Smooth the hole from both sides until the pin will enter fully with a light pressure between thumb and finger. Fit the remainder of the pins in the same way. Secure the bridge to the plate with its screws. Drill through the barrel and centre-wheel holes into the bridge to a depth of about 1 mm. Remove the bridge and, using the drillings as centres, scribe circles 0.5 mm larger in diameter than the barrels and centre wheel.

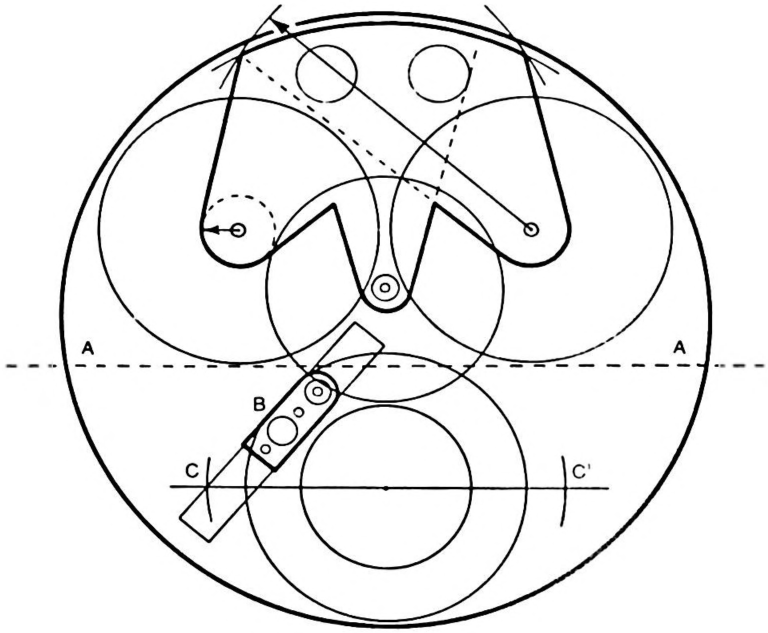
Centre on the mandrel by one of the barrel holes using the tailstock centre. Verify the centring by observing the concentricity of the scribed circle relative to the tip of the cutter in the slide rest. Turn the recess for the barrel to the diameter of the scribed circle and to a depth equal to the height of the barrel arbor measured over the pivot shoulders. The measurements must be individually taken for each barrel. Make the first cut from the centre up to the circle for the barrel diameter. When the line is reached set the slide thimble



538 Action of tool for rounding pin ends

to zero and make all further cuts short of zero by 0.1 mm. Make the final depth cut from the full diameter to the full depth and continue the cut across the diameter to finish at the centre. Long before this stage is reached the centre hole will have disappeared but this is not needed after the piece is centred ready for turning. Take a finishing cut to a depth of 0.05 mm but stop at a radius of 1.5 mm from the centre. Note the depth measurement for this cut. Repeat the process for the second barrel and make the final cut up to 1.5 mm from the centre to the depth of the final cut of the first barrel recess. The recess for the centre wheel can now be turned to the barrel depth and the bottom of all three recesses will be to the same depth.

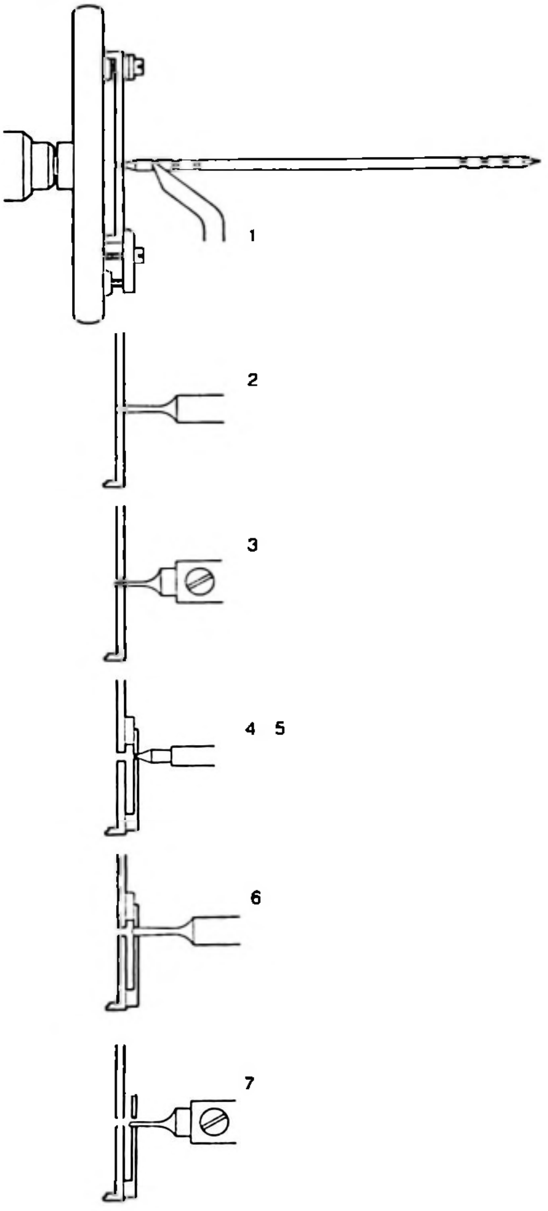
As shown in Fig 539, the plate can now be cut away below the dashed line *AA* to a more convenient size ready for drilling the top holes for the barrels and centre wheel. Note that the areas above *AA* are left to support the bridge during the drilling and boring that are to follow.



539 Preparing the barrel bridge

Put the front plate in the mandrel and centre on a barrel hole. Ensure that the clamping dogs will not obstruct the bridge. Centre quite true using the wobble stick. Open the hole to receive the boring tool in the slide rest. Bore the hole almost to the size of the barrel-arbor pivot.

Fit the bridge and make a centre mark with the tailstock runner. Drill a hole to accept the boring tool and bore the hole almost to fit the top barrel arbor pivot. Fig 540 shows the full sequence of operations. Repeat the process for the second barrel arbor and the centre pinion. Finally scribe the outline for the shape of the bridge with reference points struck with the compass from the pivot holes, as in Fig 539.



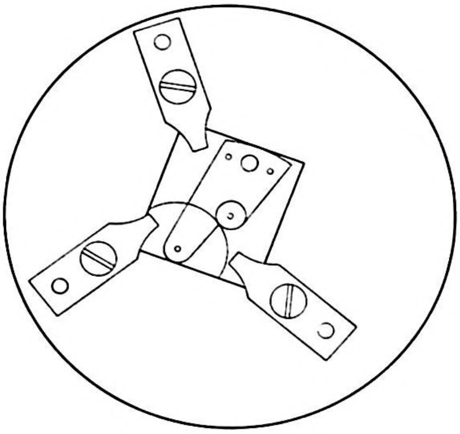
540 Sequence for boring the bridge holes concentric:

1 Centre with wobble stick
2 Enlarge the hole to receive the boring cutter
3 Bore hole almost to size
4 Fit bridge
5 Make centre chamfer
6 Drill hole
7 Bore hole almost to size

Fitting the Third Wheel

Cut a brass plate 1.5 mm thick to a size convenient to fit to the mandrel plate. Curve one edge to fit close up to the inside edge of the dial recess. Secure with a screw and two steady pins. On the upper side scribe the arcs for the position of the third-wheel drilling. There are two arcs to locate the position. First find the correct depth for the centre wheel and third pinion and, as shown in Fig 535, mark an arc *a* from the centre wheel. Next depth the third wheel with the carriage pinion and mark the arc *b*. At the intersection of the arcs make a chamfer and drill a hole 0.6 mm through the two plates. The plate for the third wheel is below the edge of the movement plate and must be supported while drilling to prevent separation under pressure of the drill.

Remove the plate and, on the steady-pin side, scribe circles for the recesses for the third wheel and carriage pinion. To ensure a secure axial engagement of the pinion the third wheel will be flush with the surface of the watch plate while the pinion will be further into the potence plate. Make the recess for the third wheel 0.7 mm and for the carriage pinion 0.9 mm with the plate fitted to the mandrel as in Fig **541**. Check that the back of the tool does not foul the edge of the recess when the cutting point is at the centre.



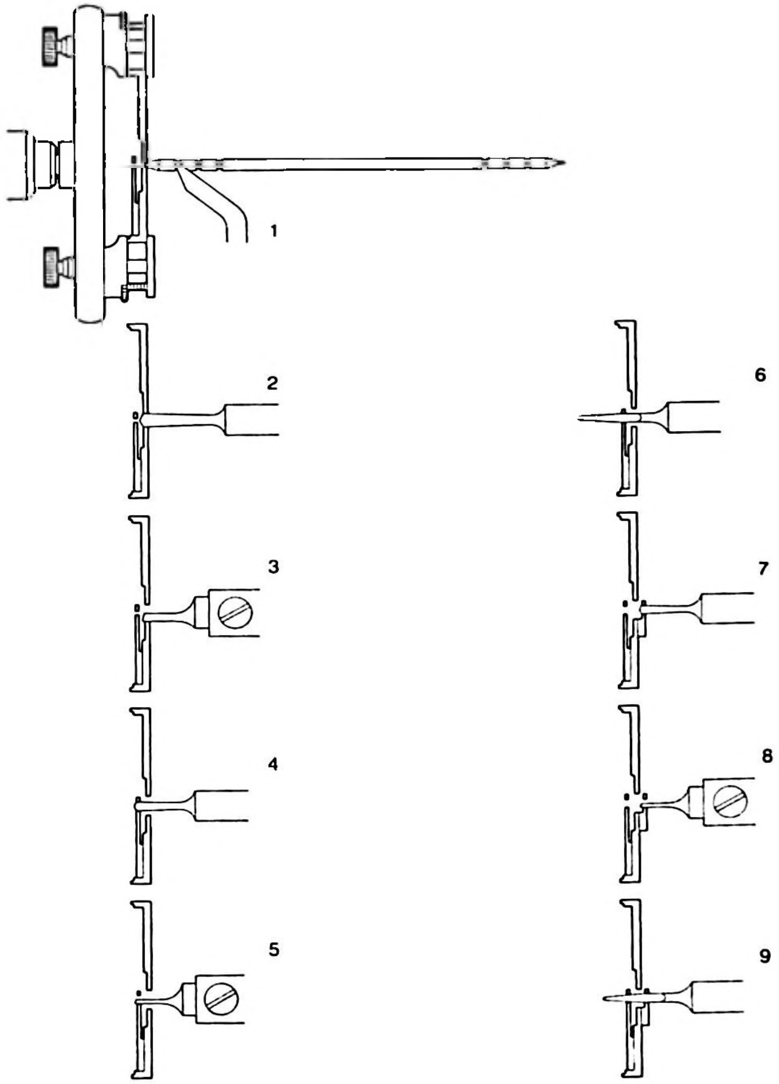
541 Recessing the third wheel and carriage pinion plate

Make the third-wheel cock from brass plate 0.75 mm thick. As shown in Fig **539**, secure to the plate with screw and two steady pins, at *B*. When positioning the steady pins be sure to leave sufficient room in the plate to open the third pinion hole to the required final diameter for the pinion. Drill through the third-wheel hole with a 0.6 mm drill. Recess the steady-pin side 1 mm for the third pinion. Note that in Fig 539 the cock is left long enough to fit to the mandrel for recessing and that its edge position must not touch the circle for the escape potence of the carriage.

Put the watch plate in the mandrel and recess the dial side to take the thickness of the third wheel, which is 0.4 mm plus 0.15 mm clearance. Fit the potence and reverse the plate on the mandrel. Centre on the third-wheel hole and make quite true with the wobble stick. Open the hole to the diameter of the third pinion plus 0.15 mm radial clearance. Through the enlarged hole open the hole in the potence to accept the boring cutter. Bore the hole almost to size for the jewel and finish with the jewel broach. Fit the cock and repeat the process which will ensure exact alignment of the holes. The sequence is shown in Fig 542.

Locating the Fixed Wheel

Re-centre the plate on the mandrel at the carriage hole. Use the wobble stick and make quite true. Enlarge the hole and bore to

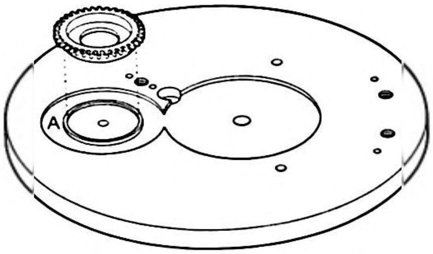


542 Sequence for boring the third-wheel holes concentric:
1 Centre with wobble stick
2 Enlarge third-wheel drilling to receive boring tool
3 Bore hole to diameter of third pinion plus 0.3 mm
4 Enlarge potence hole to receive boring tool
5 Bore hole to 0.1 mm smaller than jewel hole
6 Broach to fit jewel hole
7 Fit cock and enlarge hole to receive boring tool
8 Bore hole to 0.1 mm smaller than jewel hole
9 Broach to fit jewel hole

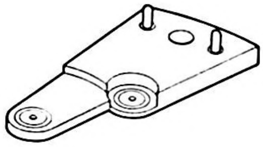
accept the carriage pinion collar. Through the hole enlarge the lower carriage pivot hole in the third-wheel potence to take the boring tool. Bore the hole almost to the diameter of the jewel. Finish to size with the jewel broach.

Recess the surface of the plate to the locating diameter of the fixed wheel and to a depth of 0.4 mm. Increase the radius of the cutter and turn the recess for the escape-wheel potence to the depth of the centre-wheel recess. As shown in Fig 543, shifting the radius of the cutter will leave a circular wall, *A*, for locating the fixed wheel.

Remove from the mandrel and drill and tap the holes for the securing screws 0.7 mm diameter. Note that the metal is thinner above the third-wheel recess on the dial side of the plate. Fix the



543 Location of fourth wheel



544 Finished and jewelled plate

jewels to the potence and cock and finally cut to shape as shown inverted in Fig 544.

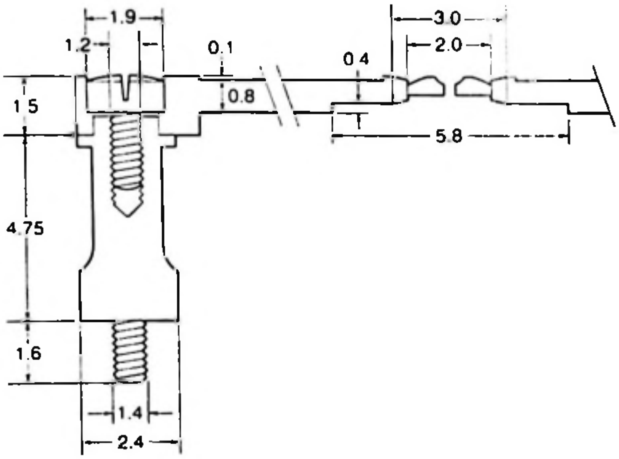
Note that the jewels are fitted before the shapes are cut out. This is because the jewels are a force fit in the brass and if the cock is thin at one edge the material may stretch and put the jewel off centre. By fitting before shaping, the brass is equally compressed on all sides.

Supporting the Carriage

The Pillars

The carriage may be supported by a bridge or a cock. Both methods are illustrated in Plates III and IV. The bridge will need pillars made in steel and threaded into the plate. The height of the bridge will be 6.25 mm, the same as the barrel bridge. The ends should be made deep enough to accept the screw heads.

Turn the pillars by the method shown in Fig 568. Suitable dimensions are shown in Fig 545. Drill and tap the holes in the plate, as shown in Fig 539, at the intersection of line CC' and the arcs struck outside the circle for the full diameter of the carriage. Ensure a full seating for the pillar flanges by observing the seating marks on the plate. Mark one pillar and its hole to avoid interchanging.



545 Dimensions for a *tourbillon* carriage bridge and pillars

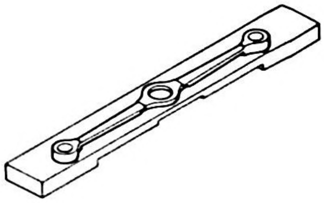
The Bridge

Mark off the centre distance of the pillar holes on a steel plate 1.5 mm thick and long enough to clamp to the mandrel plate outside the pillar hole marks. Drill the holes undersize and open one to fit the marked pillar. Mark the plate to correspond with the marked pillar. Fit to the pillar and examine the second smaller hole. If it is correctly aligned with the pillar collar it can be opened to fit. If necessary correct its position before opening to fit the collar.

Fit the movement into the mandrel and centre on the lower carriage hole. Use the wobble stick and make quite true. Fit the steel plate and secure with screws. Make a centre with the tailstock and drill a hole. Open the hole to accept the boring tool and bore the hole to 3 mm.

Shaping the Bridge

Remove from the pillars and clamp to the mandrel plate. Turn a recess in the underside 0.5 mm deep extending up to the pillar seats. Turn a further recess at the centre to a radius equal to the balance-spring stud and 0.4 mm deep. It is convenient if this work can be done on a different mandrel so that the watch plate is not disturbed before the bridge is finished.


546 Form of the carriage bridge

Scribe the outline of the final shape of the bridge on the upper surface, as in Fig **546**. Cut out and file to shape, leaving all edges with a smooth, straight grain. File the top of the arms so that they are curved to a depth of 0.1 mm to leave flat surrounds to the holes. Bevel the edges of the flats and chamfer the holes with a round cutter.

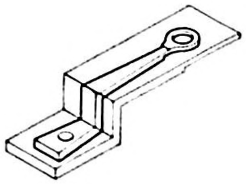
Finishing the Bridge

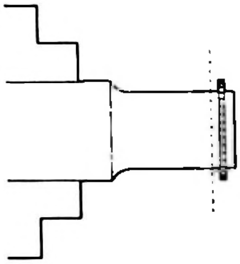
Put into an iron-wire sheath to harden in oil. Temper to a blue colour and clean the underside, screw sinks and edges with oilstone paste and iron polishers. Finish with wood and oilstone paste. Polish the chamfers with diamantine on hard brass polishers. The final finishing of the upper surfaces of the flats and curved surfaces of the arms can be left until the movement is completed.

Turn a bouchon to fit the centre hole and bevel the edge adjacent to the chamfer. Return the bridge to the pillars and secure with screws. Bore the bouchon upright, with the lower hole almost to the diameter of the jewel. Finish with the jewel broach. With a round tool, chamfer the corner of the bouchon and polish with wood and diamantine.

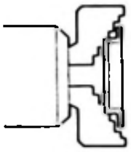
The Cock

If a cock is to be used this must be cut from the shape illustrated in Fig **547**. Scribe a centre line and drill the hole for the fixing screw. Secure to the plate and drill the steady pin holes to 0.7 mm diameter. File the pins from blued-steel wire tempered to a grey colour. Centre the hole as for the bridge hole. Cut out and finish ready for hardening. After hardening finish as for the bridge cock and leave the final polishing until the movement is completed.

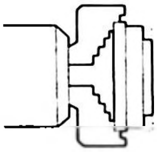

547 Form of the carriage cock



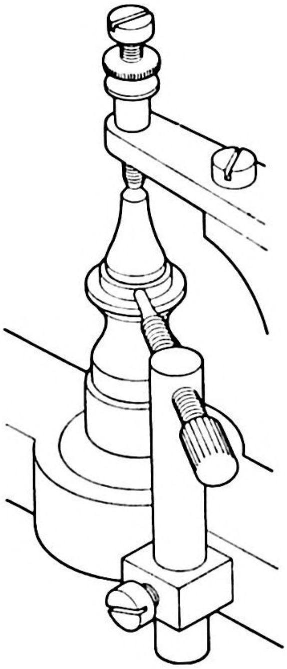
548 Machining the fourth wheel from a brass bar



549 Turning the hollow of the fourth wheel



550 Turning the base of the fourth wheel



551 Centring the blank in the wheel engine

Fit the bouchon and bore upright to the bottom hole. Finish with the jewel broach and fit the jewel. A suitable-sized jewel would be of 2 mm diameter with a 0.3 mm diameter hole.

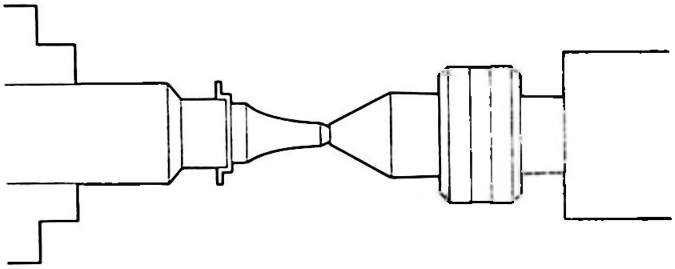
The Fixed Wheel

The fixed wheel can be turned from a bar of brass. Turn the rod to the form shown in Fig **548** and cut the teeth before parting off at the dashed line. By this means the teeth will be quite concentric with the locating base. Finally place in the step chuck and turn out the centre and make the through hole for the carriage pinion, as in Fig **549**.

If the wheel is to be cut from a disc this can be held in a step chuck. Turn the base to diameter and depth, as in Fig **550**. Reverse in the chuck, as for Fig **549**, and turn the tooth flange to thickness and diameter. Clamp lightly to the post of the wheel engine and make true at the base with the centring screw, as in Fig **551**. Tighten the clamping screw. Cut the teeth and finish the hollow, as in Fig **549**.

To cut the teeth in the lathe turn the blank as shown in Fig **551**, leaving the base oversized. Fit to a post in the headstock, as in Fig **552**, and secure with the revolving tailstock centre and a clamping cone. Cut the teeth. Finally reduce the base to the required diameter to make it true with the teeth. The final cut is taken very lightly to avoid turning the wheel on the post.

The disc can be cut and turned while soldered to the post in the headstock. Turn all surfaces as in Fig **548**. Unsolder the joint, which will be at the dashed line, and finish as in Fig **549**. Wash with soap and hot water to remove any traces of flux.



552 Method of securing the blank in the lathe

Tourbillon Carriages

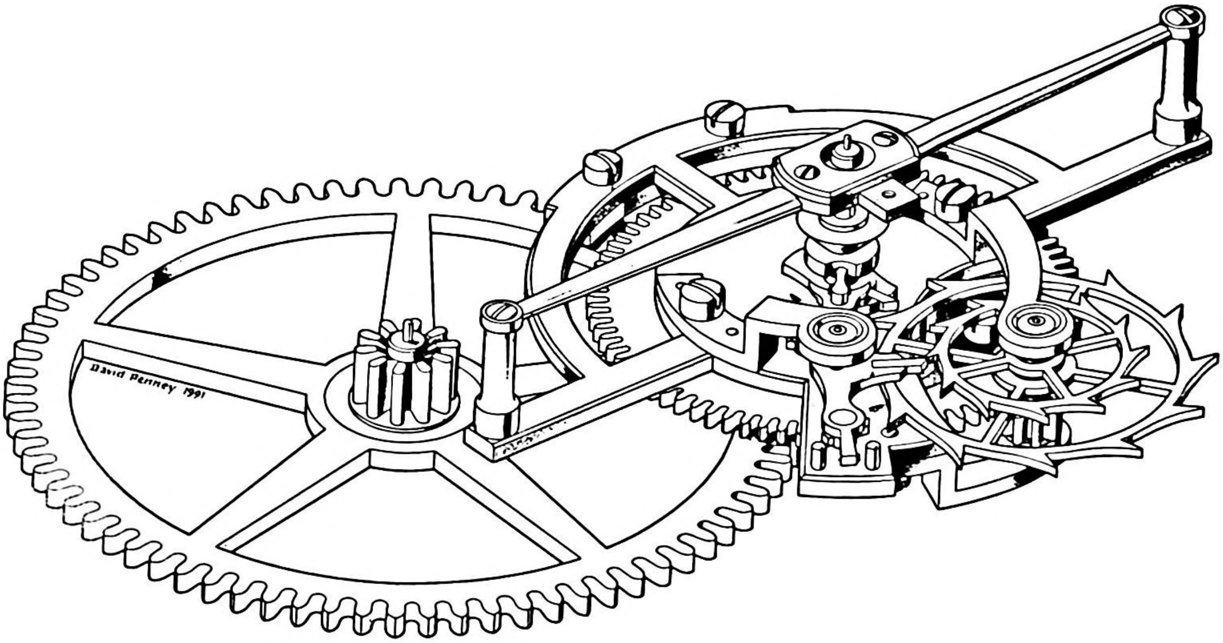
The *tourbillon*, or rotating escapement carriage, was patented by A. L. Breguet in 1801. The purpose of the invention was to eliminate errors of poise in the balance by revolving the escapement continuously to produce a uniform average rate.

Poise errors may be static or dynamic and their effect will vary with change of balance amplitude. The poise of bi-metallic balances sometimes changes with the change of temperature. The *tourbillon* carriage will effectively average all changes of rate from these causes. The close vertical rates obtainable with a *tourbillon* will last longer than similar rates from a conventional watch.

One-Minute Tourbillon

The most popular form of the *tourbillon* is shown in Fig 553 where the carriage is carried on the fourth pinion and rotates within the fixed fourth wheel. The escape pinion engages the fourth wheel and rotates as the carriage is rotated by the third wheel engaging the fourth pinion. This was the arrangement used by Breguet for his first *tourbillon*. He used Arnold's spring detent escapement with balance vibrating 18,000 times per hour.

With this arrangement the carriage will be released and locked at each vibration of the balance, which is 150 times a minute. If the lever escapement is used the carriage will start and stop 300 times a minute. The inertia will increase directly as the weight of the carriage and as the square of its radius of gyration. Obviously a small, light carriage is better than a large, heavy one. But however much the inertia is reduced it will obviously be higher than the inertia of the fourth wheel without the carriage.



553 One-minute *tourbillon* carriage with spring detent escapement

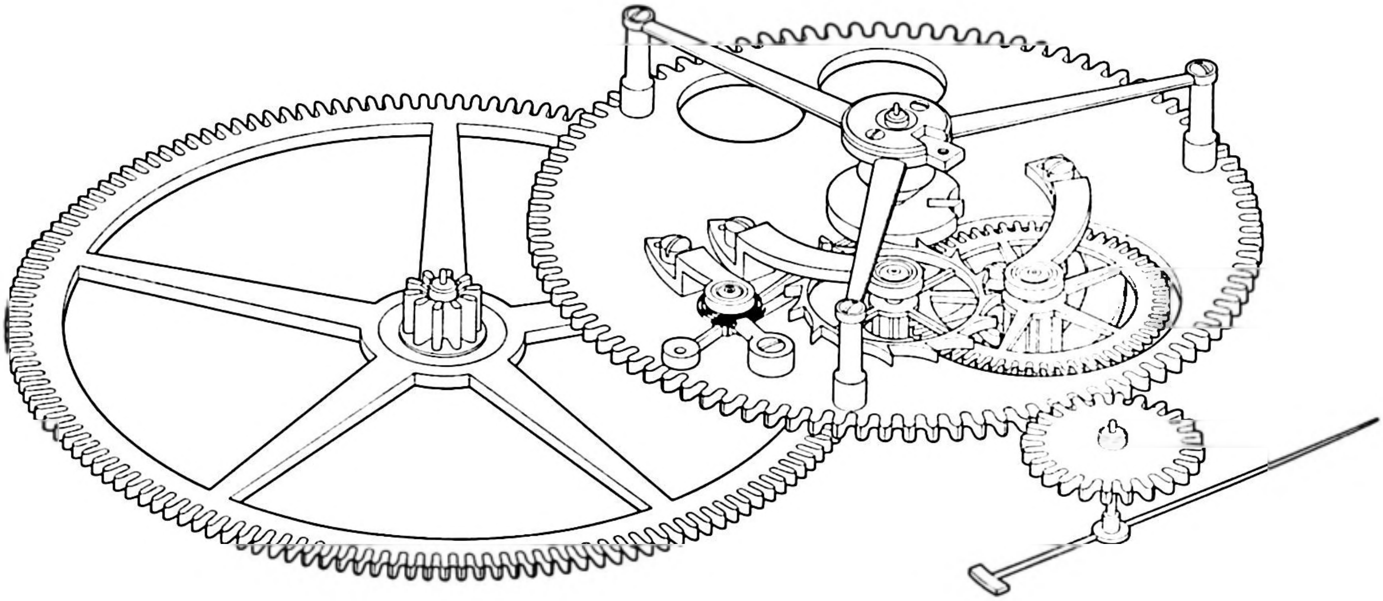
Carriage Inertia

For a given-sized balance and period of vibration a *tourbillon* watch will need a stronger mainspring than is required in a conventional watch. A double impulse escapement will need a further increase to compensate for the double inertia loss and the double reversal due to the draw.

The effects of the inertia could be reduced by making the carriage and its components smaller. This would both disproportionately increase the difficulties of construction and reduce the accuracy of timekeeping. Small balances are more affected by frictional changes and oil deterioration than larger balances. With the heavier lockings of the *tourbillon*-mounted escapement the smaller balance is more likely to set because its spring is too weak to overcome the friction of the lockings at small amplitudes.

Tourbillon carriages are usually fitted to pocket watches in which they perform well and will hold a very close rate of timekeeping for many years. The smallest known *tourbillon* is by Robert-Charrue of the School of Horology in Le Locle, Switzerland. His carriage, only 8 mm in diameter, was fitted to a watch of 19 mm diameter. The forces of inertia in such a watch would be very small but the connoisseur prefers something larger that he may see without a powerful glass. A well-constructed carriage for use in the pocket will be more pleasing to look at and will maintain better timekeeping.

A superior way to reduce the inertia is to reduce the speed of rotation. This allows the use of a weaker mainspring with consequent reduction in lost balance energy through the unlocking friction and draw reversal. Breguet made carriages with four-minute and six-minute periods of rotation. He did this by mounting the fourth wheel on the carriage which is pivoted within the fixed third wheel, as shown in Fig 554. The seconds hand can no longer be fitted to the carriage pivot and must be driven from the edge of the carriage. If the carriage rotates once in six minutes then the seconds must be driven by the carriage in the same ratio. Train calculations for *tourbillons* are the same as for conventional watches.



554 Four-minute *tourbillon* carriage with pivoted detent escapement

Karrusel

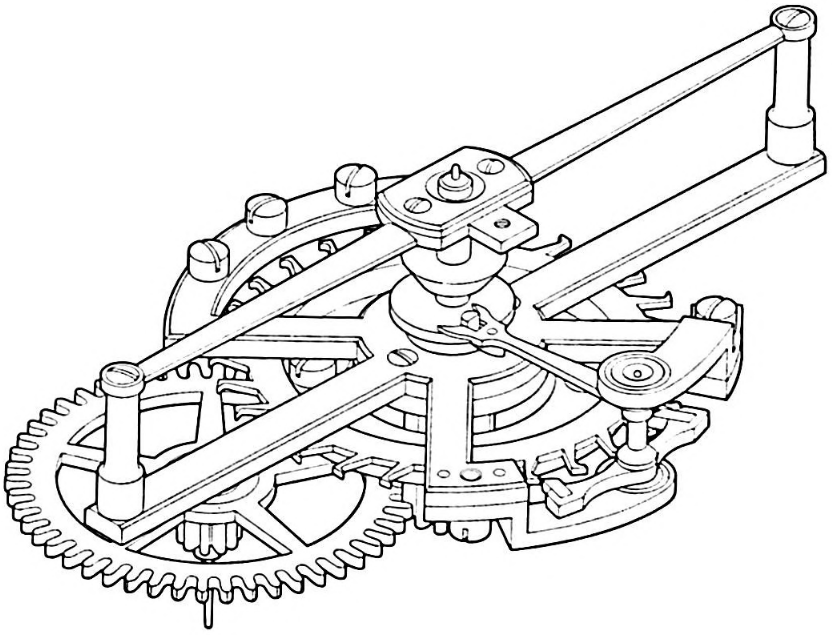
The success of *tourbillons* in observatory trials prompted Bahn Bonniksen to design a watch with a slowly rotating carriage which he called a Karrusel. This was simpler to construct and could be produced in quantity at a relatively low price. It is different in principle to the *tourbillon*. The conventional fourth wheel carries the seconds hand while the escapement revolves around it on a carriage turned by the third pinion. Because the speed of rotation of the fourth wheel is determined by the escapement, which itself is revolving in the same direction as the fourth wheel, the period of vibration of the balance must be adjusted to suit the speed of the carriage. If the chosen vibrations are 18,000 per hour and the carriage turns twice in the hour then the fourth wheel will complete two extra turns each hour. This is equal to 600 vibrations per hour and so the balance period must be reset to 18,000 − 600 = 17,400 vibrations. Conversely, if the carriage rotates in the opposite direction to the fourth wheel the vibrations must be quickened to 18,600 per hour.

Karrusels do not usually have an upper bridge or cock to support the carriage, which turns on a collar surrounding the fourth pinion. The friction of this bearing can cause the watch to stop if it is badly finished or in need of cleaning. The bearings should not be oiled, for the oil adhesion would certainly affect the timekeeping.

The Karrusel can average all the poise errors of the balance into a uniform daily rate just as well as the *tourbillon*. But for those who are not concerned with the cost of construction the *tourbillon* is altogether more pleasing in appearance.

Albert Potter

The *tourbillon* carriage shown in Fig 555 was devised by Albert Potter the celebrated American watchmaker. The lever escapement is used and the carriage supports only the balance and pallets. The escape wheel of 30 teeth is fixed to the watch plate and the pallets revolve around it. With an 18,000 train the carriage, which is fitted

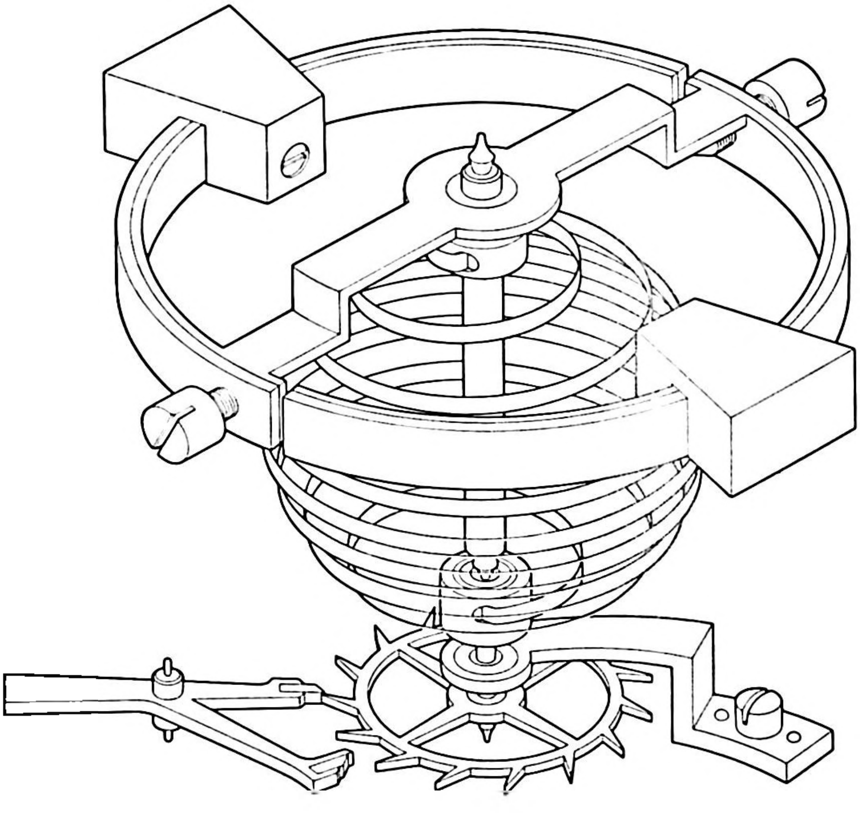


555 Twelve-second *tourbillon* carriage with lever escapement by Albert Potter

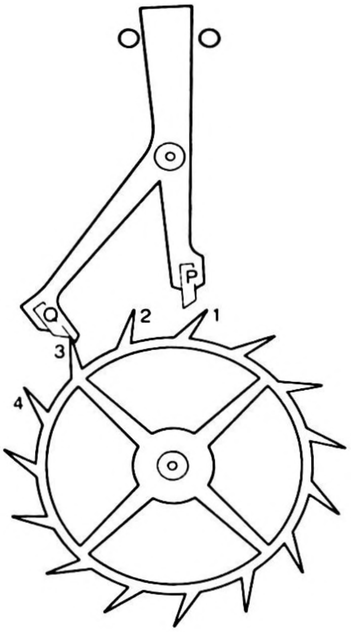
to the escape-wheel pinion, turns once in twelve seconds. Because the escape wheel has twice the conventional number of teeth the number of leaves in the carriage pinion is also doubled. This system has no advantage over slower rotating carriages but excites more interest among *tourbillon* fanciers.

A. H. Benoit

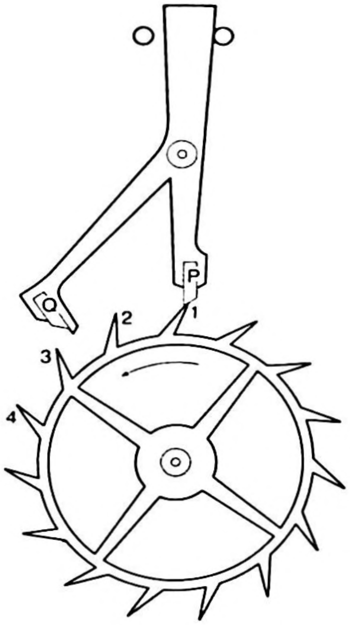
The *tourbillon* by Benoit does not have a carriage. The balance is pivoted in a bearing fitted to the upper escape-wheel pivot. The two are coupled by a balance spring, as in Fig 556. The action is shown in Figs **557a**, **b**, **c** and **d**. In the position shown in Fig **557a** the balance is vibrating clockwise and the spring urges tooth 3 into contact with locking pallet *Q*. At the end of the return vibration, with the balance turning anticlockwise, the wound balance spring will turn the escape wheel backwards and tooth 1 will turn pallet *P* to unlock pallet *Q*, as shown in Fig **557b**. During the next clockwise vibration the escape wheel will turn with the balance and tooth 2 will advance to pallet *P*, as in Fig **557c**, to complete the impulse and reset pallet *Q* into the path of the wheel teeth. This is shown in Fig **557d**, with tooth 4 about to turn pallet *Q* to reset pallet *P* into the path of the wheel teeth, as shown in Fig **557a**, ready to repeat the sequence.



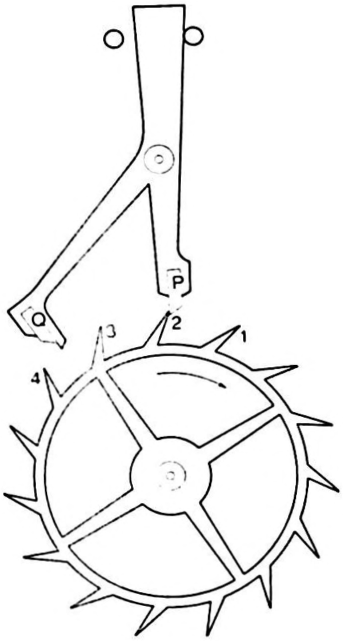
556 *Tourbillon* without carriage by A. H. Benoit



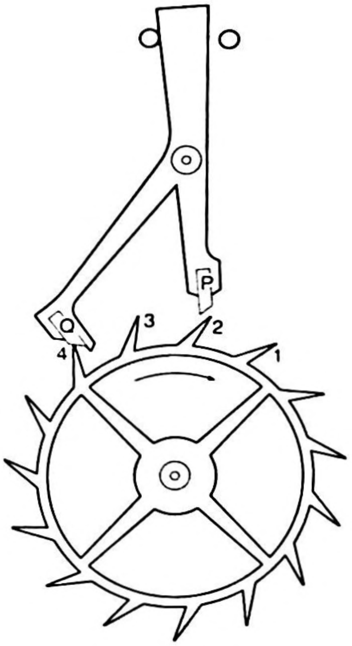
557a Tooth 3 locked on pallet *Q*



557b Tooth 1 in reverse contact with pallet *P*



557c Tooth 2 in forward contact with pallet *P* during impulse



557d Tooth 4 in forward contact with pallet *Q* prior to locking

During the impulse the balance will revolve with the escape wheel and make a complete revolution for each revolution of the escape wheel. For an escape wheel of 15 teeth with an 18,000 train the balance will turn once every six seconds. There is no carriage inertia and no unlocking friction.

At first sight this would seem to be the perfect escapement, with the addition of a revolving balance thrown in for good measure. Unfortunately it has a fundamental fault. Because the escape wheel is reversed by the balance spring to effect the unlocking the strain energy in the balance spring must equal the potential energy in the escape wheel. This can only occur at the limit of the vibration when the balance spring is fully wound. The slightest reduction of balance energy before reversal of the escape wheel will result in failure to unlock and the watch will stop.

Tourbillon Escapements

The *tourbillon* watch is expected to keep better time than a conventional watch. If its potential to maintain a closer rate for a longer period of time is to be fully exploited, it should be fitted with an escapement that does not need oil at the impulse surfaces.

Spring Detent Escapement

Breguet used Arnold's spring detent escapement in his first *tourbillon*. This has the advantage that the detent is locked in tension and cannot buckle with the impact of the locking. It is a single impulse escapement so that, in a *tourbillon*, the locking impact is heavier. But it occurs only once per oscillation so that the friction from this source and the inertia loss of the carriage are lower than for a double impulse escapement. It does not require oil.

When well designed, the single impulse is not disadvantageous. It is a delicate escapement easily deranged by unskilled handling. When used in a *tourbillon* it should not have a regulator for the balance spring. These encourage tampering and reversal of the carriage, with consequent buckling of the detent while pushing on the regulator.

Peto's Cross Detent

Breguet sometimes used Peto's Cross Detent in his *tourbillons*. This locks the wheel with the detent in tension and avoids the necessity of using Arnold's thick escape wheels with upraised teeth. The separate passing spring causes friction at the detent horn and exerts a force to oppose the detent spring.

The watch illustrated in Plate II has a detent in tension with the passing spring attached to the detent and encircling the balance axis to avoid the disadvantages of the Peto detent.

Earnshaw Spring Detent

Earnshaw's spring detent was often used in the *tourbillon*. It might be thought that the detent locked in compression would buckle but this does not happen. The watch illustrated in Plate III has an Earnshaw detent escapement. Breguet; Victor Kullberg; Charles Perret; Albert, James and Georges Pellaton; and Alfred Helwig all used the spring detent escapement in the *tourbillon* carriage with success. However, a regulator should not be fitted to the balance spring of a *tourbillon* with an Earnshaw escapement.

The pivoted detent was used by some Swiss makers, notably Guinard. It does not need the length of the spring detent and can be poised with a counterweight. It is more robust than the spring detent, and a regulator can be used for the balance spring without risk of damage to the escapement. It is not necessary to oil the escape-wheel teeth.

Lever Escapement

The lever escapement was used by Breguet for his final series of *tourbillon* watches made between 1810 and 1820. He used circular lockings for his pallets and so avoided the double reversal and friction of the unlocking. It was used by Nicole Nielson in his *tourbillons* made in the first quarter of the twentieth century, and it was again taken up by Sidney Better for a series of watches made for the Northern Goldsmiths Company in the early 1930s.

It is a robust escapement and a regulator can be used without any risk of damage by carriage reversal. But the need for oil at the lifting surfaces is a disadvantage and will cause deterioration in the rate that will not occur with an oil-free escapement.

Daniels Co-Axial Escapement

This is particularly suitable for use in the *tourbillon* watch. It is a double impulse escapement of robust construction and needs no oil at the lifting surfaces. It is self-starting from both the run-down condition and from accidental stoppage. The watch illustrated in Plate IV is fitted with this escapement.

Making a Tourbillon Carriage

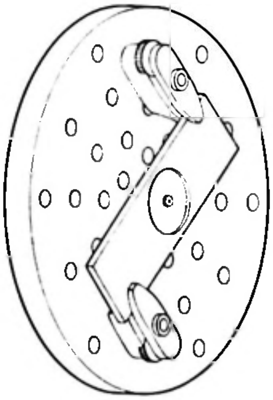
The watches illustrated in this book have either two-armed or three-armed carriages. The two-armed carriage is lighter but requires greater care in making to avoid any errors of uprighting.

It should be noted that the balance staff of a *tourbillon* watch is of necessity very short. In the carriage described it is only 3.7 mm in length for a balance wheel of 22.6 mm diameter. If the staff is only 0.01 mm out of vertical the balance will lose 0.06 mm clearance at one side. The designed clearance is only 0.20 mm and an error of 0.06 mm would almost double the clearance at the opposite radius and look very bad.

Whatever escapement is chosen the same methods of construction apply to the carriage. Escapements with pivoted components can be marked off with the depth tool. The spring detent requires special attention and the method of planting will be described.

Preparing the Plate

The carriage is to be made from oil hardening, annealed carbon steel. Test a piece to be sure that it will harden. If it can be obtained as a disc of 26.5 mm diameter and 1.3 mm thick the work will be simplified. Put the disc in the lathe and turn to 0.8 mm thick, leaving a boss at the centre 3 mm diameter and 0.5 mm high. If a



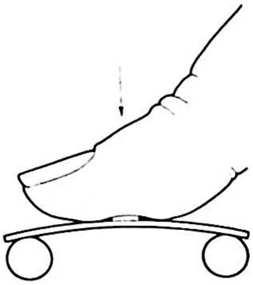
558 Preparing the disc for the carriage plate

disc is not available it can be prepared from a strip clamped to the mandrel plate, as in Fig 558.

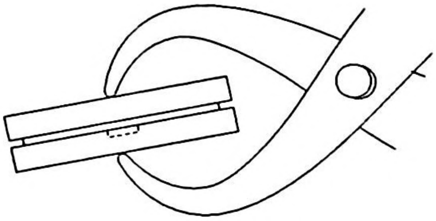
To relieve any stresses in the turned surfaces, raise the disk to dull red heat and allow to cool slowly. Check both sides for flatness and uniformity of thickness. If it is bowed, place it on two supports and apply pressure with the thumb (see Fig 559). Prepare two steel plates of some 2 mm thickness; one with a recess to receive the boss of the disc. With the disc clamped between the plates, raise to dull red heat and allow to cool slowly to set the disc flat (Fig 560).

Finally, finish the surface quite flat to uniform thickness and smooth with an oilstone slip (see Fig 561).

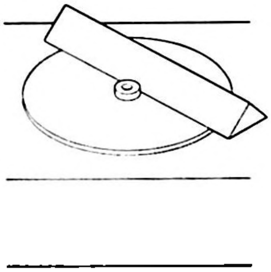
Again measure the thickness at several places. If uneven mark the high spots on the underside with a pencil and file flat until the thickness is equal. Finish with the stone slip. The finished disc must be quite flat and smooth and of uniform thickness at 0.6mm overall. Finishing the underside with the stone will mark the edge of the boss but this will be reduced later and the marks erased.



559 Flattening a bow in the disc



560 Flattening a dished disc



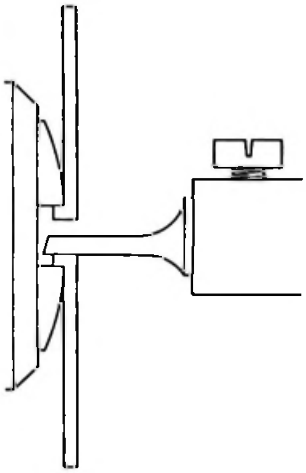
561 Finishing the disc with an emery stone

Centring and Marking Out

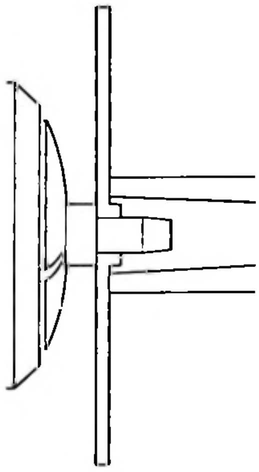
Hold by the centre boss in a collet in the lathe and drill a hole 1.5 mm diameter. Bore the hole with the slide rest to 0.2 mm less than the required diameter of the jewel setting, as shown in Fig 562.

The type of jewel setting may be a matter of personal preference. It is possible that the old-fashioned screwed-in settings would be preferred. If so, provision must be made in the diameter of the boss for the screw threads. It is simpler to fit a press-in setting with the endstone secured by a spring clip. With this system the end clearance of the staff can be adjusted if necessary and the accuracy of the setting is assured.

Check the progress of the boring with a plug guage and stop when the hole is 0.2 mm undersize. Turn a piece of brass rod and fit the disc by pressing it up to a shoulder with the tailstock runner, as in Fig 563. Turn the boss true and to its final diameter of 2.7 mm. Lock the headstock with the index. Make a radial mark for the pillar position with the point of the slide-rest cutter. Turn the headstock 180° and make a second mark. If the carriage is to have three arms make three marks at 120°. One further mark is required to mark the radius upon which the escape wheel will be planted. This should be symmetrical between two arms. At a radius of 11.95 mm cross the pillar marks with the compass.



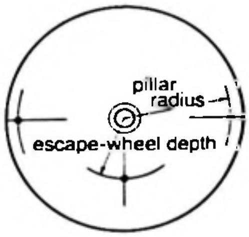
562 Boring the centre hole



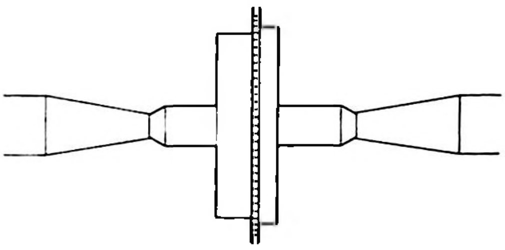
563 Mounting the disc in the lathe

The Escape-Wheel Holes

Make the fourth wheel as described. Fix the wheel to an arbor in the depth tool, as shown in Fig 564, and find the correct engagement for the escape-wheel pinion. Strike the arc for the depth from the centre hole of the carriage plate. Drill the holes for the pillars and the hole for the escape wheel 0.5 mm diameter. The drilled plate is shown in Fig 565 for a carriage with two arms.

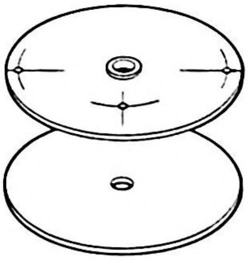


565 Drilling the pillar and escape-wheel hole

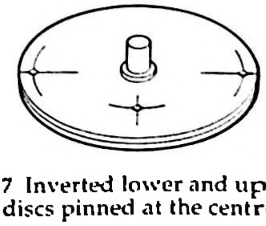


564 Fourth-wheel arbor for use in the depth tool

Prepare a second disc for the upper plate 26.5 mm diameter and 0.7 mm thick with a centre hole the same diameter as the lower plate. Make a mark near the edge and lay the lower carriage plate face down on the upper plate so that the mark registers with the marked pillar hole, as in Fig 566. Part off the brass pin that was used to support the lower plate in the lathe and lightly drive it into the holes of the two plates. This will hold them securely together for drilling. As shown in Fig 567 the lower carriage plate is inverted above the bridge plate. This must now always be the relative position of the two discs. Drill through the two discs at the pillar holes with a 0.6 mm drill. Tap the hole in the lower carriage disc with a No. 12 Martin gauge or the equivalent fine thread.



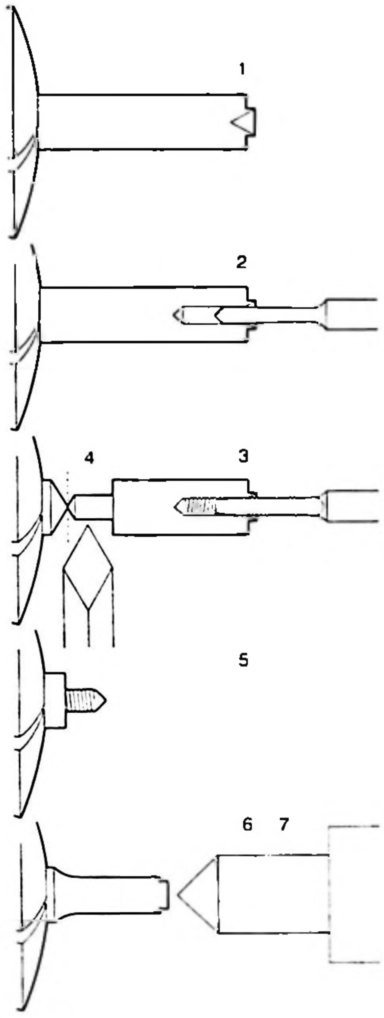
566 Inverted upper disc with locating mark



567 Inverted lower and upper discs pinned at the centre

The Pillars

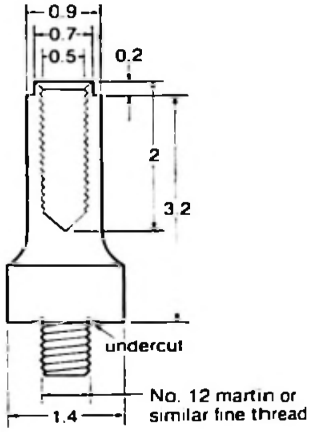
Turn the pillars from annealed carbon-steel wire. Thread the posts with a No. 12 Martin or similar fine thread and drill and tap 0.5 mm for the bridge screws. Great care is needed when tapping the hole which must be a full 2 mm deep and full threaded to a depth of 1.5 mm.



568 Sequence for making the carriage pillars:

1 Centre
2 Drill to required depth
3 Thread
4 Part off with the graver
5 Thread the post
6 Centre the hole
7 Turn collar true and to diameter

Note that the posts are threaded fully up to the flanges which are undercut in the corners. Leave the bridge locating collars a little over diameter and length and finish the mouth of the hole with a chamfer so that a centre can be used after hardening. The stages of turning and drilling are shown in Fig 568. Harden in oil and temper to very pale blue. Clean up with oilstone powder and wood. Clean out the thread with an oily tap and rinse in benzine. Shorten the posts so that the threads are flush with the underside of the carriage plate and mark the end of one to avoid interchanging after the bridge is made. Finally grip as in position 6 of Fig 568. Make true with a centre in the drilling or with the heel of the graver and finish the bridge collars to size. The dimensions are given in Fig 569.

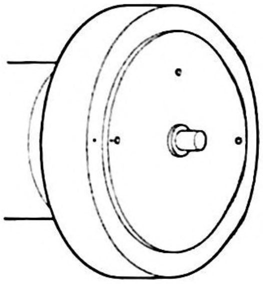


569 Dimensions of carriage pillar

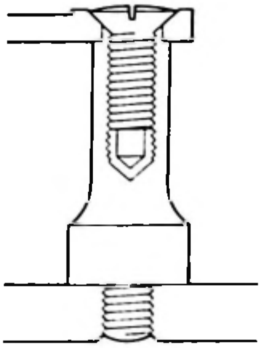
The Upper Bridge

Screw the pillars into the lower plate. Ensure that they are properly seated on the plate by removing and observing the pressure marks of the flanges. These should be clearly defined circles impressed on the plate. Finally tighten the pillars with brass pliers. Open one of the 0.6 mm pillar holes in the bridge plate to fit the pillar. Remember that the orientation of the plate is marked with the appropriate pillar in its hole. The other hole or holes should be in alignment. If so, open them to fit and the plate will seat on to the collar flanges of the pillars. If there is any misalignment it will be very small and can be corrected by opening the hole in the required direction. If any misalignment exceeds the amount required to open the hole to fit, then the work is faulty and should be started again. It is fundamental to the success of the carriage that the upper bridge plate holes fit closely.

The bridge must now be reduced in thickness to leave a boss for the jewel setting at the centre. Fit it to a brass chuck in the lathe centred on a pin turned true and closely fitting the centre hole. Drill a hole between the pillar positions for a drive pin and reduce the plate to 0.35 mm leaving a boss 2.6 mm diameter at the centre, as in Fig 570. To avoid losing the marked pillar hole make a mark on the chuck and, after the reduction, re-mark the hole with a chamfered point. The mark will now be permanent. Smooth both sides of the disc with an oilstone slip and chamfer the pillar holes to take the heads of the screws. Make the screws with countersunk heads to fit the chamfers. Turn a start on the screws to help to stand them in the holes for assembly, as in Fig 571.



570 Preserving the marked position of the upper bridge



571 Bridge screw with starting threads removed

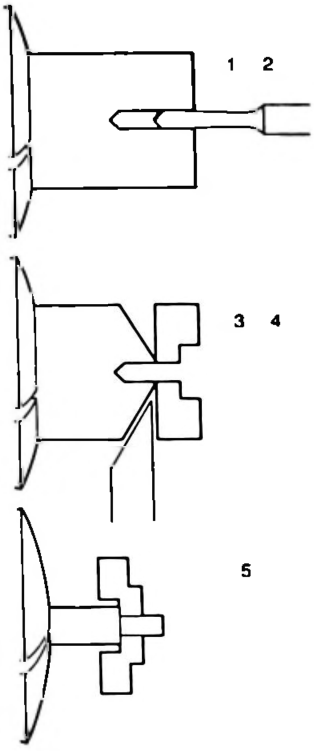
Finishing and Uprighting the Holes

Put the lower plate, complete with pillars, in the mandrel plate and centre with the wobble stick, as in Fig 11. There must be no visible movement at the free end of the stick. Tighten the dogs firmly and re-check the truth of the stick. Bore the hole to size, less 0.05 mm, and finish with a jewel broach located by the tailstock and liberally lubricated to prevent the surface of the hole tearing. Fit the bridge and secure with screws. Repeat the boring and broaching. The two holes will now be perfectly aligned.

Fitting the Pinion

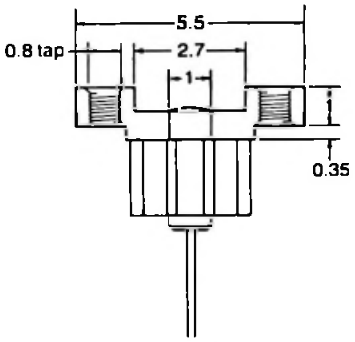
The pinion collar is located by the lower plate boss. This was made true with the hole in the early stages of preparation. Make the collar in the order and to the dimensions shown in Figs 572 and 572a. The pinion post is a 0.01 mm oversize fit in the hole. The completed collar is a light friction-fit on the plate boss.

Scribe a circle on the plate to mark the radius of the fixing screws, and a line across the diameter the screws will occupy. The orientation of the line will depend upon the type of escapement. Fit the



572 Sequence for making the carriage pinion collar:

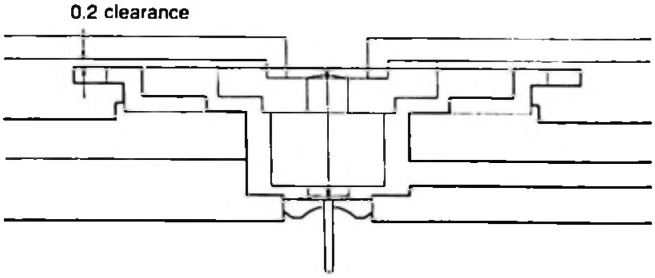
1 True the face
2 Drill
3 Fit to plate boss
4 Part off with the graver
5 Reverse and turn pinion face



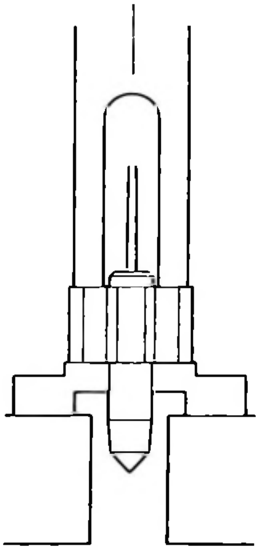
572a Dimensions of the carriage pinion collar

collar and drill through. Thread the holes in the collar 0.8 mm diameter and open the holes in the plate to pass the threads. Harden and temper the collar. Clean out the threads with wood and oilstone paste. Before fitting the pinion the collar must be finished. Fit it on the arbor in the lathe and polish the surfaces as required.

The length of the pinion is derived from the face of the lower carriage jewel in the potence to the top of the fixed fourth wheel, plus 0.2 mm clearance for the carriage, as in Fig 573. Turn the pinion to length leaving the arbor or post for the collar long and with a centre point. The arbor is a 0.01 mm oversize fit in the collar. Fit up in the staking tool and tap the pinion into the collar with a hammer and a punch in contact with the pinion face, as in Fig 574. Polish the face of the pinion and finally turn away the unwanted arbor.



573 Carriage clearance above the fourth wheel

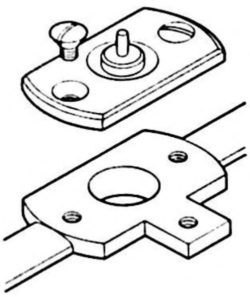


574 Pressing in the carriage pinion

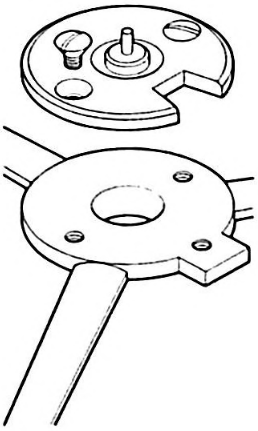
Fitting the Upper Pivot

The upper pivot is located by the jewel setting hole in the bridge and secured by screws from above. In Figs **575a**, b and c it is shown turned, complete with flange, from steel hardened and tempered. Turn this to form in the stages shown in Fig 576.

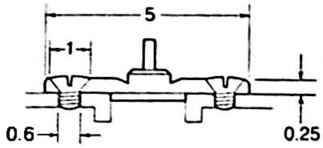
Mark the underside of the bridge plate close up to the boss with a pointed chamfer and drill the holes for the pivot flange screws 0.5 mm diameter. Fit the pivot into the jewel setting hole and drill through the flange. Tap the holes in the bridge 0.6 mm and open the holes in the flange to pass the threads. Sink the heads of the screws flush with the top surface of the flange. Harden and temper to deep blue. Finally part off the post, and the pivot is completed. Note that the shape given to the flange in Fig **575a** is for a two-armed carriage. For three arms the flange is left circular but will need a notch for the stud, as shown in Fig **575b**.



575a Upper carriage pivot

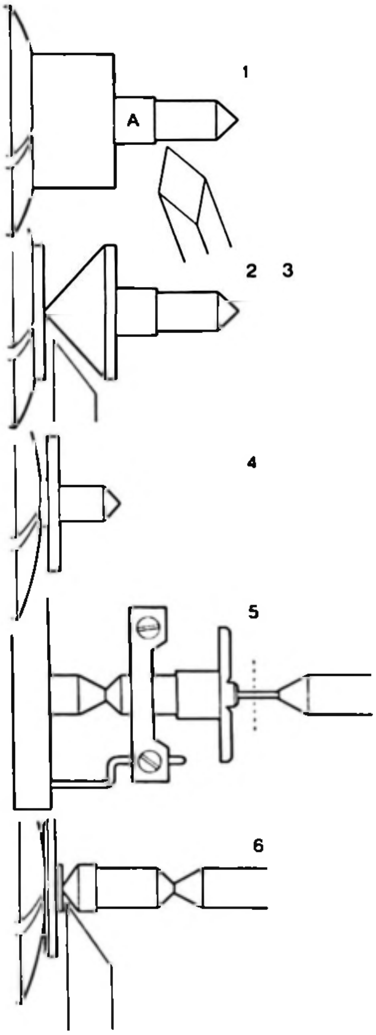


575b Upper carriage pivot



575c Dimensions of upper pivot

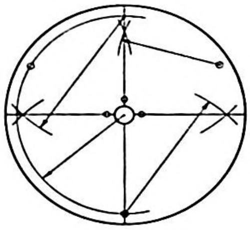
The carriage can now be assembled and tried in the frame. It should run quite true in flat and round with 0.2 mm clearance above the fixed wheel and 0.2 mm clearance beneath the supporting bridge or cock. Before fitting the escapement it is useful to cut out the arms of the bridge to give access to the components.



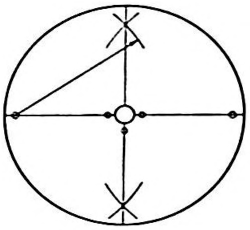
576 Sequence for making the upper carriage pivot:

1 Turn *A* to fit upper bridge centre hole
2 Turn seating flange face
3 Part off with the graver
4 Reverse in collet and reduce pivot arbor while preserving the parting off centre
5 Turn pivot between centres
6 Reverse and part off surplus

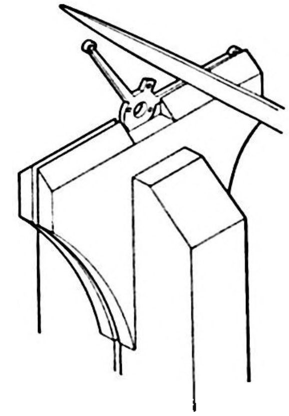
Mark and drill the hole for the stud. This will be placed symmetrically to the pivot flange holes. Scribe light arcs from the pillar holes with the compass to find the radial position of the hole. Figs **577a** and **b** show the methods of finding symmetrical radii applicable to the carriage plates. Drill the hole at a radius suitable to the shape



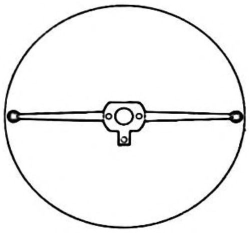
577a Method of marking symmetrical radii for a three-armed carriage



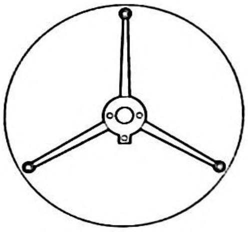
577b Symmetrical radii for a two-armed carriage



579 Filing the bridge arms



578a Form of upper bridge

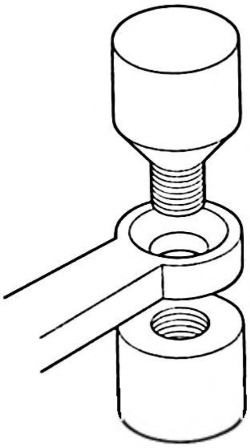


578b Form of upper bridge

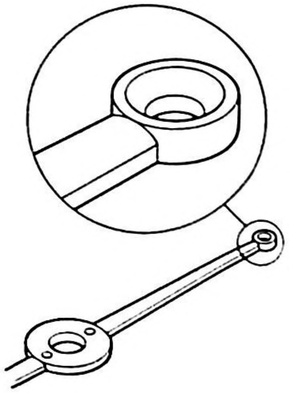
and diameter of the terminal curve of the spring. Tap 0.6 mm diameter.

Scribe the outline of the arms and centre boss with stud bracket, as in Figs 578a and b. Saw out the component with great care because the material is soft and easily distorted. Hold only by the unwanted material so that any stresses induced by sawing will not reach the component. Use a pair of hand tongs with jaws especially shaped to grip the arms while avoiding the boss. Fig 579 shows the bridge gripped for filing. Use sharp files to avoid the need to press the file into contact. Bring the edges gradually down to size in turn. Do not finish one arm before starting the next. The hand will become better accustomed to the increasing delicacy of the component if it is gradually reduced overall. Fit hardened steel plugs into the pillar holes to be sure they are finished round and with square edges, as in Fig 580. Make all surfaces very smooth and finish the sides of the arms with a longitudinal grain. Finally file the upper surfaces of the arms to a slight curve as shown in Fig 581, to emphasize the flat circle preserved by the steel plugs at the edge of the pillar hole. In its final form the bridge is delicate and easily distorted. It will need fitting many times before the carriage is finished. It will withstand this better when it is hardened but first it must be checked to ensure freedom from distortion.

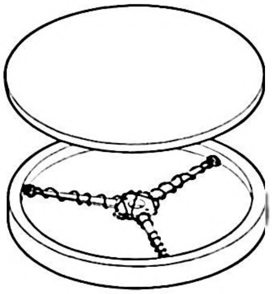
Centre the pillar plate on the mandrel. If the three-armed bridge fits without need of pressure to any of the arms it will be true in the hole with the securing screws fitted. The two-armed bridge will fit although it may be distorted. Fit the screws and check with the wobble stick. Eccentricity can occur only at 90° to the pillar radius. Make any necessary correction to the appropriate arm by gentle pressure in the required direction. If the filing is done carefully there is not the least danger of distortion.



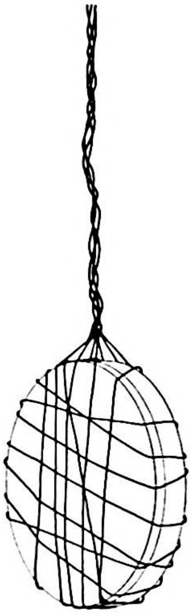
580 Hard steel plug for shaping the pillar holes



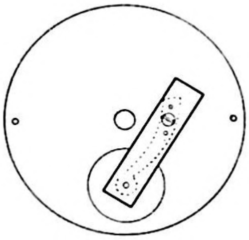
581 Curved upper surface of the bridge arms



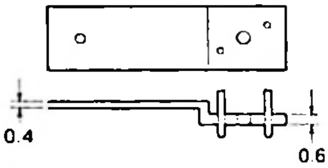
582 Insulating the arms from contact with the hardening box



583 Hardening box with iron-wire handle



584 Preparing the steel for the escape-wheel cock



585 Elevation and temporary steady pins of escape-wheel cock

Hardening the Bridge

Hollow out two copper discs to make a covered box to contain the bridge. Wind thin iron wire loosely around the arms to prevent them touching the copper. Lay the bridge into the hollow of one disc, as in Fig 582, and cover with the second. Bind the two together with strong iron wire leaving a long handle, as in Fig 583.

Rotate the box slowly in the flame while suspended by the handle above a vessel of about 100 mm diameter and containing at least 150 mm depth of water. When satisfied that the colour of the box is uniformly bright red release it to fall vertically into the water. Remove the bridge from the box, place on a 'blueing' pan with some small bright steel pieces and heat to a pale blue. Hardness in the carriage is not required and will leave it unnecessarily brittle. Left at a pale blue colour it will be hard enough and more resistant to accidental damage.

The surfaces should now be cleaned overall and the edges left with a straight grain. Prepare the curved top surfaces of the arms with crushed oilstone paste ready for polishing when the carriage is finally completed.

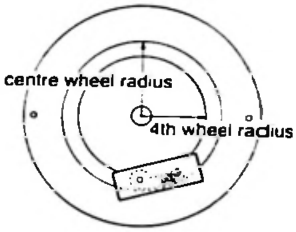
Fitting the Escape Wheel

Scribe a circle for the diameter of the escape wheel on the surface of the lower plate. Mark off and drill the position for the cock screw. Tap 0.8 mm diameter. Secure a piece of steel 1.4 mm thick to the plate so that the free end covers the escape-wheel drilling, as shown in Fig 584. Drill two holes 0.4 mm diameter and fit temporary steady pins. The cock must be quite firm and incapable of movement. Drill through the escape-wheel hole from the underside through the cock using the same size drill. Remove the steady pins and reduce the height of the foot of the cock to 0.6 mm and the thickness of the table to 0.4 mm. Refit the steady pins and the cock will appear as in Fig 585.

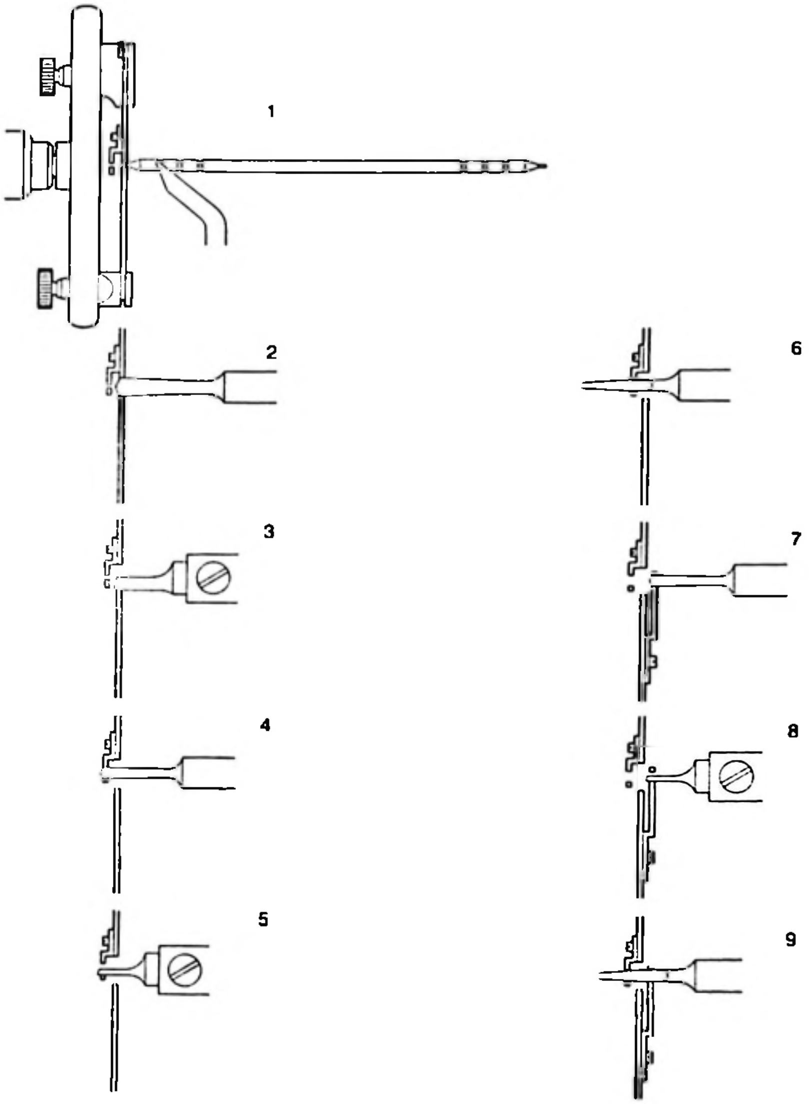
On the underside of the plate scribe a circle for the diameter of the fixed fourth wheel. The escape-wheel potence must be fitted outside this radius. Secure a piece of steel 1.45 mm thick with steady pins and a screw 0.6 mm thread diameter. Drill through the escape-wheel hole in the plate as for the cock. This potence will be very small and will be secured to that part of the plate between the escape pinion and detent. It must be secured at a radius sufficiently great to avoid touching the fixed wheel teeth. This will require an offset to the bottom escape-wheel pinion jewel to bring it beneath the teeth of the fixed wheel. The height is 1.45 mm to clear the recess in the watch plate. The potence will run level with the centre wheel and must not clash with this. The radial space for the foot is limited to the room available in plan between the centre wheel and fixed wheel. Mark on the carriage in addition to the circle for the fixed wheel a further circle to indicate the radius of the edge of the centre wheel. The potence must fall safely between these two circles with adequate clearance of, say, 0.15 mm radially. If it is thought that this point is somewhat laboured it should be remembered that if a mistake is made in planting the cock the carriage will be ruined.

The steel piece is shown fitted in Fig 586 with an indication of its final shape.

File the foot to 0.5 mm and the table to 0.4 mm thickness. With the potence in position put the plate in the mandrel and, with the wobble stick, make the escape-wheel drilling true. Enlarge the hole with a 2 mm drill. Take care that the drill does not jump through the hole and damage the potence. Open the hole further with the boring tool in the slide rest until it is as large as it can be while leaving sufficient metal at the steady pin holes of the potence. Through the enlarged hole open the potence hole to 1.2 mm by drilling to 0.9 mm, boring to 1.1 mm, and finishing with a jewel broach. Fit the cock and repeat the process for the top hole. The correct sequence of operation is shown in Fig 587, 1 to 9.

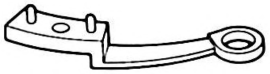


586 Escape-wheel lower potence

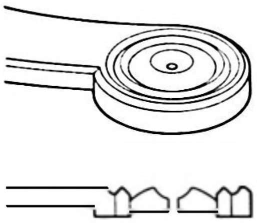


587 Sequence for boring the escape-wheel cock and potence concentric:

1 Centre escape-hole drilling
2 Enlarge hole to receive boring tool
3 Enlarge hole to largest possible diameter
4 Enlarge potence hole to receive boring tool
5 Bore potence hole to 0.1 mm undersize
6 Broach potence to final diameter
7 Fit cock and enlarge hole
8 Bore hole to 0.1 mm undersize
9 Broach cock to final diameter



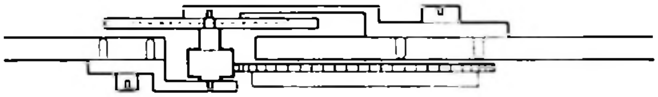
588 Reduced thickness of cock table



589 Brass bouchon for jewel setting

Scribe the outline of both cock and potence on their surfaces and file to shape. Reduce the thickness of the table of the cock to 0.25 mm but leave at 0.4 mm for the jewel setting, as in Fig 588. Harden and temper to a pale blue colour. Clean the surface overall with oilstone paste and iron polishers. Finish the edges with wood and oilstone paste to produce a soft, even-grained finish. Degussit stones are very useful for the initial stages of cleaning. Finish all flat surfaces with sharp diamantine on iron polishers while resting the component on a hard cork block. Chamfer the top edge of the hole and polish with a suitably shaped brass polisher. Fit a brass bouchon to the potence hole and refit the potence with its temporary steady pins to the plate. Refit the cock and put the plate in the mandrel. Centre on the cock hole. Remove the cock and open the potence bouchon to 0.7 mm with the slide rest. Finish to 0.8 mm with the jewel broach. Fit a bouchon to the cock and repeat the process. Fit the jewels with 0.13 mm holes to the bouchon and the plate is ready for the escape-wheel pinion. The polished chamfer of the cock combined with the bevelling of the bouchon will produce an attractive finish to the work, as in Fig 589. It is important that a watch does not look like the product of an engineer.

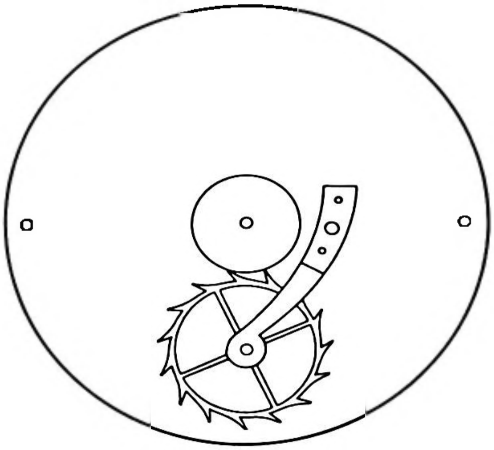
Make a dummy pinion to establish the overall length of the escape pinion and the height of the escape wheel, as shown in Fig 590. The top surface of the teeth of the wheel will be level with the underside of the jewel setting. The clearance of 0.15 mm is provided by the reduced thickness of the table. Adjust the dummy pinion so that it can be used as a direct comparator gauge for the escape pinion. Turn in the pinion and mount the finished wheel. The pinion will need 0.05 mm end shake to the pivots. This will reduce slightly when finally finishing the carriage plate.



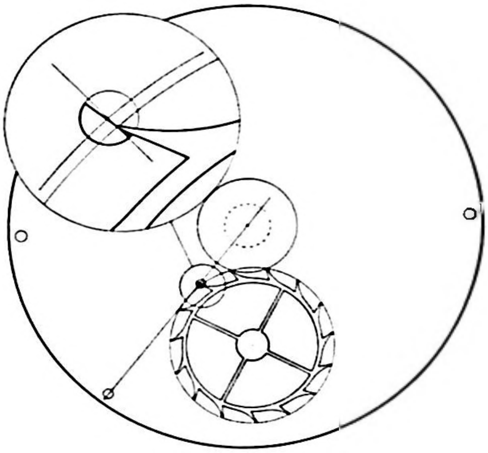
590 Dummy pinion for taking escape-pinion dimensions

Fitting the Detent

Make a dummy balance roller with a post to fit the lower balance jewel setting hole. Carefully reduce the diameter of the roller until the post can be fitted into the hole while lightly touching two escape-wheel teeth, as in Fig 591. On the outer edge of the circle for the escape-wheel diameter make a mark beneath the tooth at the detent locking point. Drill a 0.4 mm hole at the mark. Fit a half-round brass pin into the hole and, if all is correct, the escape-wheel teeth will touch at the two points of the roller and at the pin, as in Fig 592. Check that the pin is accurately planted by reducing the roller until the escape-wheel teeth are free. The clearance of the two teeth at the roller should be equal when the locking tooth is resting on the flat of the pin. If this is not so the hole can be drifted with a file in the required direction and made round with a broach. When



591 Locking the escape wheel



592 Marking the position for the detent foot hole

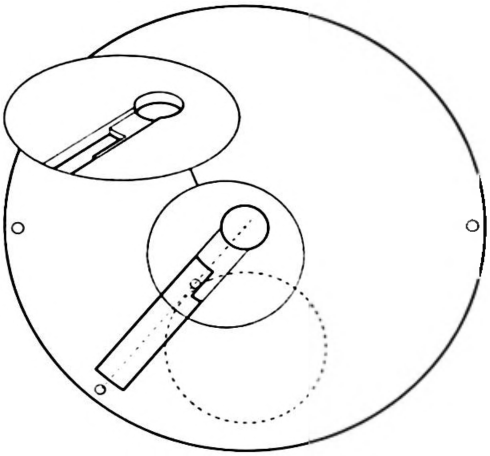
the carriage is finished the hole will be cut away but the edge nearest the escape wheel will be the banking depth for the detent. The detent will bank at the locking-stone pipe which will be a little larger in diameter than the stone. Therefore a little drifting of the hole in the early stages will do no harm provided the banking depth is not increased.

Note that by drilling the hole at the outer edge of the scribed circle the depth of the locking is reduced. Scribe a line from the centre of the jewel setting hole at a tangent to the escape wheel and up to the edge of the plate. Drill the foot hole on this line and tap 0.5 mm, as in Fig 592.

Prepare a piece of steel with a hole 0.5 mm diameter at one end. Remove the escape wheel and screw the steel to the carriage at the detent foot hole. Make a second drilling through the locking-pin hole in the plate from the underside. The steel is now the template for drilling the pipe and foot holes for the detent.

The plate must now be cut away to make room for the detent. Fig 593 shows the area to be cut away. Note the radial position of the banking generated from the locking-pin hole and the channel milled out of the centre to make freedom for the detent horn and passing spring. The detent can now be made. When the detent steel is sufficiently reduced to make a trial fitting to establish the clearance beneath the escape wheel, the steady pin holes can be drilled. Fit a brass locking pin in the pipe and secure the detent foot by its screw to the plate. Check that the clearances are correct with the escape wheel and dummy roller in position. Drill the steady pin holes 0.3 mm through both detent and plate. The detent can now be finished and hardened and the locking pin made and fitted. Note that when filing the temporary locking pin the half diameter must be measured. It is deceptive to gauge by eye and an incorrect dimension will upset the progress of the work.

For an escapement with pivoted components the depths are marked off from the escape wheel and balance centres. The same



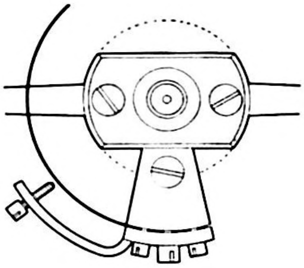
593 Making room for the detent

methods of fitting the cocks and potences for the escape wheel applies for the additional components.

Fitting the Balance and Spring

The balance jewels must be fitted to the carriage plate and bridge before making the balance staff. The settings will be pressed into the holes with the jewelling press. Once fitted to the bridge hole the jewel setting can remain in position. With a smooth broach lightly polish the wall of the hole to prevent the steel tearing the brass setting. It is important that there is no sharp edge to the hole. Press in the setting, making allowance for the locating shoulder of the top carriage pivot. Do not burnish the bottom setting hole which is soft and liable to distortion. Press in the setting. It will need to be taken out again when the plate is hardened and should then be replaced with a new one.

Make the impulse and unlocking rollers and make and fit the jewels. Turn a dummy staff to establish the heights and diameters of the various shoulders. Use the dummy as a direct comparator gauge to make the final staff. Fit the balance and rollers and poise the assembly. Make the spring collet and fit the spring. Vibrate to time and form the terminal curve.



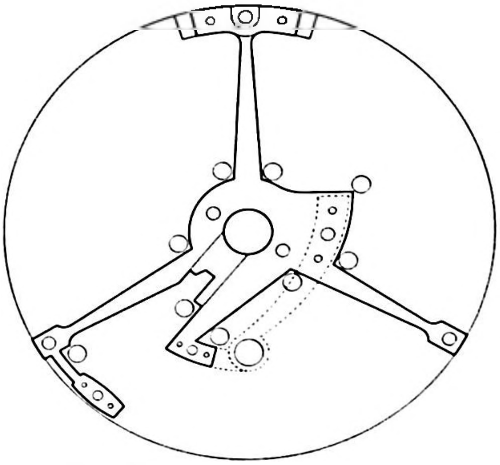
594 Balance-spring clamp

The spring will fit below the top of the balance rim and so there is not much height for the terminal curve. The clearance between the stud and the spiral can be increased by using a clamp, as shown in Fig 594. This is also shown in Fig 656 with the details of its construction. For a two-armed carriage this will locate against the side of the upper pivot flange, as in Fig 575a. For three arms it will locate in a notch cut in the flange, as shown in Fig 575b. Because the escapement is a spring detent there is no regulator and the curb screw can help to equalize the vertical and horizontal rates.

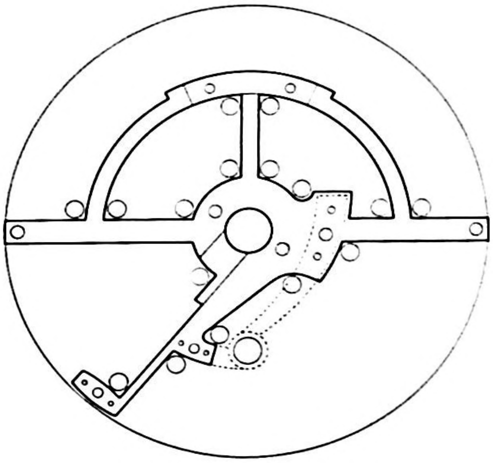
At this stage the balance can be brought to within ten seconds of time by adding or subtracting weight. Make any alterations equally to diametrically opposite weights to maintain the poise and keep the full adjustment available for final regulation. Note carefully the position of the end of the spring in the clamp which must be removed from the spring and refitted to the bridge ready for poising the carriage.

Finishing the Carriage

All that remains to be done is to remove unwanted weight from the carriage and poise the assembly.

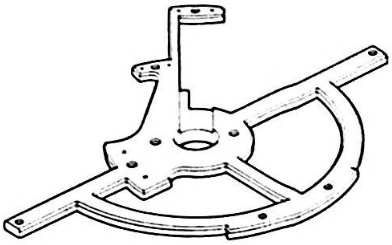


595 Final form of three-armed carriage plate



596 Final form of two-armed carriage plate

Scribe lines to indicate the final shape and drill 1 mm holes in the corners to allow the saw to enter. Figs 595 and 596 show the final shape for three-armed and two-armed bottom carriage plates as used in watches illustrated in Plates III and IV. File up to the lines using sharp files needing little pressure. Leave the edges with a longitudinal grain from the files. This final work requires files with sharp, clean edges that will reach into the corner. Bevel the edges with a smooth file to an angle of about 25° from the horizontal. Finish the bevel smooth with a burnisher with sharp corners. Take the burnisher right into the corner to meet the adjacent angle and produce a clean, sharp appearance, as in Fig 597.



597 Bevelled edge finish to upper surface of plate

Assemble the carriage completely with the exception only of the balance and spring but include the clamping stud. Place on the poising tool and note the lightest position. Cut a small piece of gold of suitable size, shape it and then stick it to the carriage with a smear of beeswax. Note that in Fig 596 a semicircular bracket was left for this poising weight and in Fig 595, for the three-armed carriage, a bracket at the end of the arm. The position of the weight will vary with the type of escapement and some anticipation is necessary to ensure a sufficient amount of metal is reserved for its fixing. In the early stages of poising, the weight will be too heavy and will fall to the low position. Move the weight until it takes up the lowest position of rest on the poising tool. Gradually reduce the weight until the period of vibration of the carriage, rocking on the poising tool, is four seconds. Drill the weight and the bracket. Tap the bracket 0.6 mm diameter and screw the weight into position. Re-check the poise. The weight should still rest at the lowest position but the rocking period will be slower. The final poising can be done when the carriage is finished.

Dismantle the carriage and push out the bottom jewel setting. Harden in a copper box as for the upper bridge. If the same box is used be sure it is not warped. Air gaps will cause oxidation and scaling and can result in uneven cooling with consequent warping of the carriage plate. Temper to a pale blue colour and clean overall with oilstone paste and iron polishers. Polish or grain the top surface flat while resting on a cork block. Polish the bevel. This was left smooth from the burnisher and will polish up quickly with a brass polisher and diamantine. Lightly smooth the wall of the jewel setting hole and push in a new setting adjusting the height to suit the balance staff.

It remains to finish polishing the bridge and the screws before assembling the carriage complete with balance. Finally complete the poising of the carriage assembly and bring the balance to time. The balance was left in static poise after the intermediate timing and the position rates will be within ten seconds. This does not matter with a *tourbillon* and needs no correction.

Bring the horizontal rate to within plus five seconds on the timing machine and the carriage will be ready for rating and final adjustment.

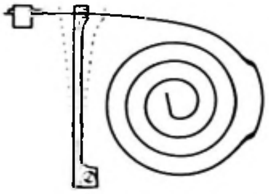
11

THE BALANCE AND SPRING

Temperature Compensation

The watchmaker today has little difficulty in compensating for change of temperature. Modern materials offer simple solutions to what was, until the twentieth century, the watch adjuster's most complex problem.

With a plain balance and steel spring a watch will lose in heat and gain in cold. The greatest part of the change in rate is due to the change in elasticity of the spring. Early attempts to compensate were made by shortening the active length of the spring for a rise in temperature and lengthening it for a fall in temperature. This was done with a bi-metallic strip of brass and steel soldered or riveted together and fixed at one end to the watch plate, as shown in Fig 598. The free end carried pins to traverse the balance spring near the stud. When the temperature rose the greater expansion of the brass curled the strip away from the stud effectively to shorten the active length. The reverse occurred for a fall in temperature.

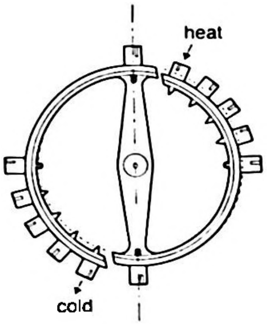


598 Bi-metallic compensation curb

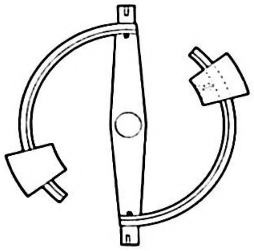
The effect on the timekeeping was extremely complex. The spring, after adjustment for isochronism to suit the escapement error, was deranged by the change in length made to correct the temperature error. Only the most exceptionally determined efforts of John Harrison, its inventor, and Thomas Mudge, its subsequent champion, succeeded in making it work successfully. Their success was not based on any serious scientific understanding of the problems but rather more by intricate adjustment of one error against the other. The adjustments, once completed, are not permanent and the rate will be lost when the watch is dismantled for cleaning.

Compensation Balance

A more practical solution was offered by John Arnold's compensation balance with the bi-metallic strips formed into curves and screwed to a cross bar in the form of a split rim. This system separated the compensation adjustments from the balance spring adjustments and continued in use for high-grade watches from



599 Balance with bi-metallic rim



600 Weights for temperature adjustment

1782 until the middle of the twentieth century. A modern example is shown in Fig 599. The inner rim and cross bar are of steel while the outer surface of the rim is of brass. As indicated by the dashed lines the radius of gyration increases for a fall in temperature and decreases for a rise in temperature. With this system, compensation can be very closely achieved by adjusting the position of the screws in the rim.

Under the influence of Earnshaw early English pocket chronometers and almost all English marine chronometers adopted two diametrically opposed weights for compensation adjustment, as shown in Fig 600. These offer continuous adjustment as against the step by step adjustment of the movable screws.

The effect of transferring weight to or from the free end of the rim is to enhance the change in the radius of gyration of the balance with change of temperature. If the watch is slow in high temperatures the weight must be moved towards the free end of the rim where it will be carried inwards to reduce the radius of gyration. For a gain at high temperatures the weight is moved nearer the fixed end of the rim where the change in radius is smaller.

Middle Temperature Error

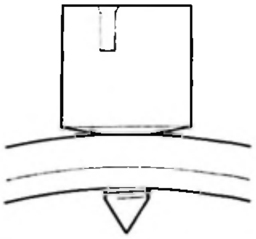
The adjustment cannot be exact for all temperatures due to the differing characteristics of the effect of temperature change on the balance and spring. Neither the change in the elasticity of the spring nor the effect of the change in the radius of gyration of the balance is directly proportional to the change in temperature. The differing characteristics combine to compensate only at one high and one low temperature. Between these two temperatures the watch will gain and outside them it will lose. The exact relationship of the two temperatures depends on the choice of temperatures for which the adjustment is made. If the high temperature chosen is 36 °C and the low 4 °C the watch can be adjusted to these temperatures but will show a gain at intermediate temperatures, called the middle temperature error. This will amount to approximately two seconds in twenty-four hours. If the choice is changed to 42 °C and 10 °C the middle temperature error will change. If the watch is required to keep time at a middle temperature it can be adjusted only at one other temperature to keep the same time. The temperature error will then appear at the opposite temperature extreme.

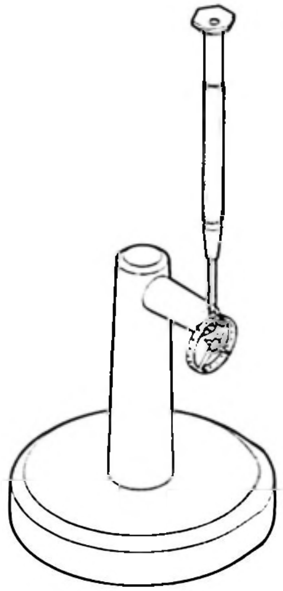
Adjusting the Balance

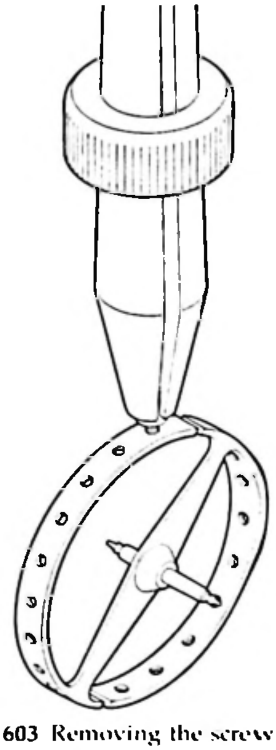
If the balance is not perfectly true in the concentricity of the rim any adjustment for temperature will effect a change in rate and the watch must be checked for twenty-four hours to establish the new rate before testing the adjustment for temperature. The operation is most tedious and time consuming and has caused even experienced adjusters considerable anxiety in the closing stages lest some ill-considered move set the work back instead of advancing it to conclusion.

During the work on the balance great care is needed to avoid distorting the rims and putting the assembly out of poise. The screws should be checked to avoid the possibility of the underside of the head distorting the rim by binding on one side. The screws of high-grade English watches were chamfered under the head to prevent this, as shown in Fig 601. Move only opposite pairs of screws of equal weight to avoid upsetting the poise of the balance. Use a gallows support, as shown in Fig 602, and slacken the screws with the screwdriver before transferring them to the selected hole with a screw-head tool, as in Fig 603. Retighten with the screwdriver. The amount of adjustment required will depend upon the ratio of thickness of brass to steel in the rim and can only be determined by trial.

For balances with sliding weights, shown in Fig 600, move first one weight by the estimated amount required, and re-poise the balance by moving the second weight. To avoid confusion mark the underside of one of the weights with a small chamfer. Always make the initial adjustment with the marked weight and re-poise with the unmarked weight.


601 Screws for temperature adjustment


602 Slackening the screw


603 Removing the screw

Temperature Tests

During the early stages of adjustment the watch can be placed alternately in the oven and refrigerator for successive twenty-four-hour tests. The time taken to make adjustments will be sufficient to allow the watch to return to a middle temperature. When the rates at high and low temperatures are within five seconds of each other, time must be allowed for the balance and spring to stabilize for each temperature change before beginning the twenty-four-hour test. At this stage twelve hours of acclimatization is sufficient but, in the final stages, it is better to allow twenty-four hours.

A particular fault of this type of balance is the near certainty of the balance going out of poise with change of temperature. The errors arising from this fault did not show in competitive trials because the edge rates were taken at a middle temperature.

Trials were increasingly dominated by the Swiss in the 1920s and 1930s. They chose their watches for trial by selecting the best pieces from a production of thousands. In this way much time was saved and success assured, both in the horizontal and vertical position rates.

Guillaume Steel

Although cut compensation balances are no longer made for watches, they are still available from manufacturers' old stock in Switzerland. The best type are called Guillaume after the inventor of the special steel used in their construction. Guillaume steel is alloyed with nickel to reduce its coefficient of expansion.

Brass and Guillaume steel rims change the radius of gyration of the balance to follow the requirements of the change in elasticity of the balance spring more closely. By this means the middle temperature error is reduced to less than half a second in twenty-four hours.

Limitations of Cut Balances

In addition to any views the maker of individual watches today may have about producing an accurate and worthwhile watch, he has also his customer's feelings to contend with. A very close rate of timekeeping is expected from a hand-made watch and means of checking the rate are now readily available. It is all very well for a watch to perform satisfactorily while on static test but it must also perform well in the pocket where the temperature will be high enough to expose any poise error in the compensation rims.

The best bi-metallic balances were produced by specialists whose experience, combined with metals and equipment developed especially for their purpose, resulted in high-grade, fault-free balances. Their work was augmented by the developed skills of the adjuster and to repeat their combined success today without prohibitive expenditure of costly time will need exceptional understanding of the requirements.

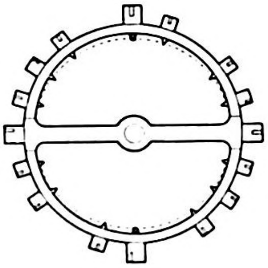
Temperature Compensating Alloys

The problems of adjustment for temperature compensation are almost eliminated by the use of one of the auto-compensating alloys now commonly used for balance springs. The two most successful are Elinvar and Nivarox. The elasticity of both these materials remains almost constant throughout the temperature range that a watch is subjected to in ordinary use. The degree of compensation of the material depends upon the processes of manufacture, including the amount of hot and cold working of the alloy and the degree of precipitation of the elements during final heat treatment of the finished spring.

The residual errors remaining amount to only a few seconds per day over a temperature range of 4 °C to 36 °C. Some batches of wire have no error. The extent of the error is important to the maker of mass-produced watches and he will only use wire that suits his timekeeping tolerances. Modern wrist-watches are not subject to extremes of temperature when worn and if they are not worn at night they are usually kept in a warm room. The small, remaining errors will have little opportunity to affect the rate noticeably and will in all probability be swamped by the position errors that are to be found in the mass-produced watch.

Residual Error Correction

Once the magnitude of the error, which may be wholly due to the balance, has been discovered, it can be corrected by an auxiliary compensation applied to the balance. The function of the auxiliary is to change the radius of gyration of the balance to compensate the error. The two principal ways of doing this are by using an ovalizing balance or small bi-metallic attachments.


604 Bi-metallic ovalizing balance

The ovalizing balance was used extensively by the Hamilton Watch Company of America who used an Invar cross-bar soldered to a stainless steel rim, as shown in Fig 604. The length of the bar remained constant with change of temperature and caused the rim to become oval with expansion or contraction of the stainless steel.

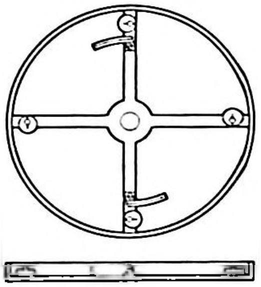
The weights in the rim could be moved to match the change in radius of gyration to the residual error. If the weights were equally distributed around the rim and the watch lost in heat, the weights could be moved to a position nearer the immovable axis. For a gain in heat the weights were moved near the axis of greatest ovality.

The use of the ovalizing balance with screws in the rim brings two disadvantages. The first is the restriction of the diameter of the balance rim causing a reduction in radius of gyration. The second is the air disturbance caused by the rapidly moving screws as the balance vibrates. This increases the energy losses of the balance and increases the effects of change of barometric pressure.

The diameter of a balance without screws can be greater and, for the same inertia, lighter in weight. The resultant reduction in pivot friction will reduce isochronal errors in the vertical positions, and further advantage in this direction can be had by reducing the diameter of the pivots without risk of damage from a heavy balance.

Balance with Compensation Attachments

The balance shown in Fig 605 is simple to make, very light and without peripheral protrusions to cause disturbance. Auxiliary compensation is by short bi-metallic attachments and regulation by eccentric gold weights. The assembly is brought to time in the horizontal position by washers beneath the weights and then checked for temperature compensation. The attachments are initially left longer than is known, by experience, to be required. This causes a gain in heat that can be corrected by shortening the attachments by filing the free ends. After each alteration the watch is again brought to time by washers and the compensation re-checked at 36 °C and 4 °C.



605 Daniels balance with bi-metallic attachments

An Elinvar spring is used and with this combination the rates at 20 °C and at the two extremes can be equalized with no sign of middle temperature error. During temperature adjustment it is not necessary to bring the watch exactly to time before re-checking. A rate within five seconds per day at the middle temperature is close enough.

The same procedure is applicable to Nivarox springs and with both types the attachments can be made with the brass and steel reversed to compensate a gain in heat. Once it is established that the error in heat is the same magnitude as the opposite error in cold, the cold tests can be discontinued.

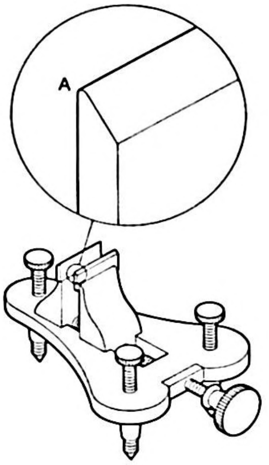
To prevent moisture condensing on the watch during cold tests it must be kept in a wooden box and allowed to rise to room temperature before the box is opened. A small domestic refrigerator will serve for the cold test while an insulated wooden box with a thermostatic switch in series with a low powered electric bulb will be sufficient for the hot tests.

Adjusting the Attachments

The rate checks must be made at twenty-four-hour intervals with the watch quite flat and fully wound at the start of each test period. This is most important if the rates are not to be confused by isochronal errors. After each alteration to the attachments the balance is re-poised to avoid an accumulated error that might be difficult to remove.

If during the first test in heat the watch loses, then it will be necessary to add weight to the attachment. This can be done by fitting a screw into a threaded hole in the attachment in the same manner as in a bi-metallic balance. Alternatively, the attachment can be changed for a longer one. This would be more effective because the weight will be added at a more advantageous distance from the fixing. Adding or subtracting weight will affect the timekeeping and the balance must be readjusted to suit. Once the compensation is correct for the balance and spring material it can be repeated, to close limits, by measurement and adjusted to completion quite quickly.

Add or subtract from one attachment only and alter the balance weights to bring the balance back to poise. Repeat the process on the other side and this will avoid excessive timekeeping errors after each adjustment.

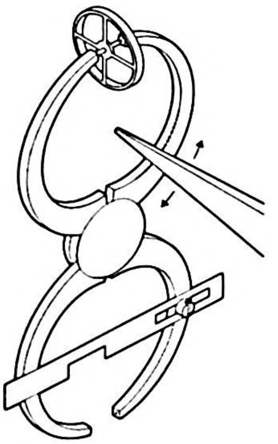


606 Balance poising tool

Poising after Adjustment

Use a poising tool of the type illustrated in Fig **606**. Agate or other hard stone edges work better than steel. The edges are better slightly radiused, as in Fig **606a**. Sharp knife-edges are easily marked, especially if made of steel, and the balance will stop rolling, although it may not be possible to detect the fault in the edge with an eyeglass. Steel edges must be checked for magnetism.

The balance can be poised in the callipers, as in Fig **607**, with the friction of the pivots reduced by stroking the serrated limb of the callipers with the tweezers. The knife-edged tool will produce a better result and the balance can be placed on the jaws with the tweezers more easily than it can be put in the callipers. Whichever method is used the balance should not be touched with the fingers. With a good poising tool and some care the balance can be brought to within ten seconds in all positions. By careful poising after each adjustment for temperature the rate can be kept within twenty seconds and so quickly brought to time for each trial, which will simplify the work of final regulation.



607 Poising in the callipers

The work of adjusting is made simpler and confusion avoided if the rate is brought to within five seconds before each trial. This can be done quickly and conveniently with the timing machine. If a large alteration is necessary in the early stages and weight must be removed, the eccentric quarter nuts can be reduced and a check made on the timing machine. If weight is to be added the exact amount can be ascertained quickly by placing washers on the timing nuts and securing them with a smear of oil. They will hold sufficiently well to enable a check to be made on the timing machine. When satisfied that the timekeeping is within regulation by the weights, the washers can be properly fitted and the balance rinsed clean in benzine ready for the twenty-four-hour test. This method will speed the process of finding the correct amount of weight and will avoid wear to the friction fit of the adjusting weights that may occur with too frequent removal.

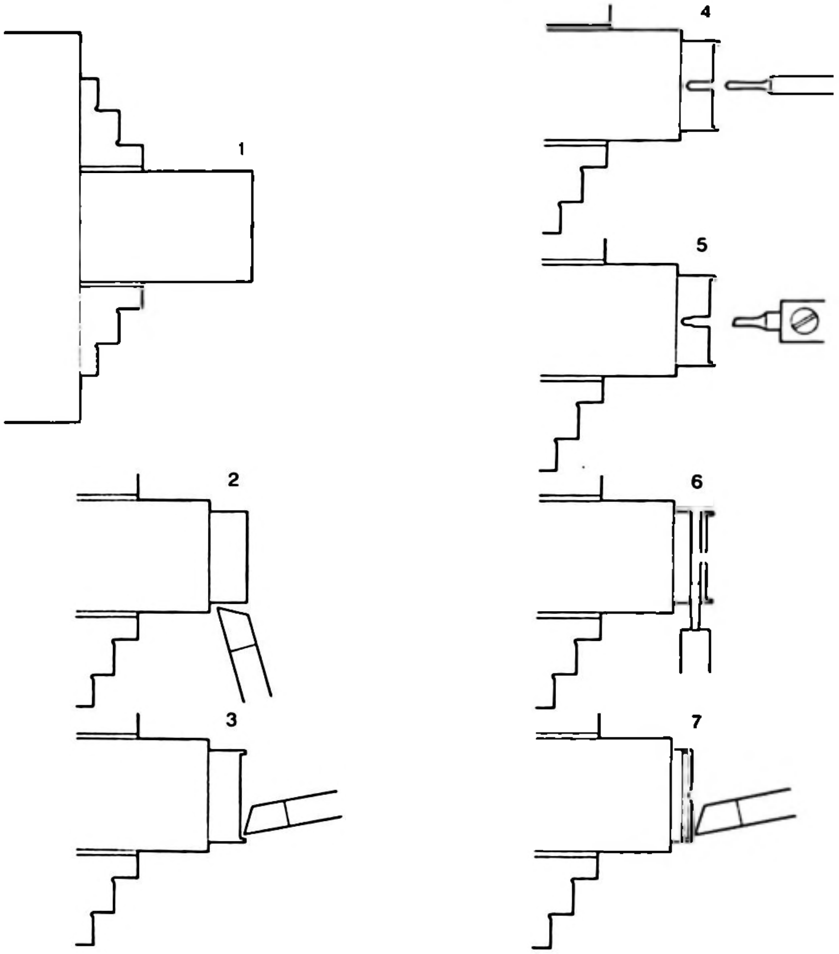
The length of the balance spring must not be altered to correct the timekeeping during temperature adjustment. To do so would disturb the provision made for isochronism when fitting the spring.

Balance Wheels

Making the Daniels Balance

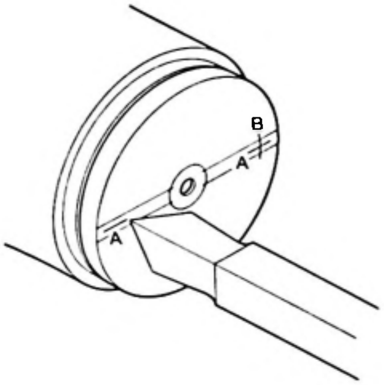
Modern balance wheels are mono-metallic and simple to make. Effects of change of temperature are compensated for in the balance spring. Earlier balances were bi-metallic in order to compensate for effects of temperature variation in the balance spring.

Stainless steel is a most useful material for mono-metallic balances. It can be obtained in the form of bars or rods of many convenient sizes. The most suitable type is free cutting and non-magnetic. The balance may be turned to dimension and parted from the bar or turned from a disc parted from the bar. Fig 608 shows the sequence for making a simple balance from a bar in the lathe. Note that the base is left a minimum of 1 mm thick during parting to avoid possible distortion from the cutting-tool pressure.

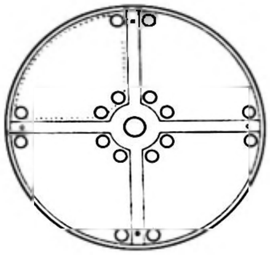


608 Sequence for making Daniels' balance:

1 Face bar true
2 Turn to diameter
3 Turn recess for rim
4 Centre and drill
5 Bore drilling to final diameter
6 Part from rod at 1 mm oversize thickness
7 Fit inverted to bar and turn underside to final required thickness



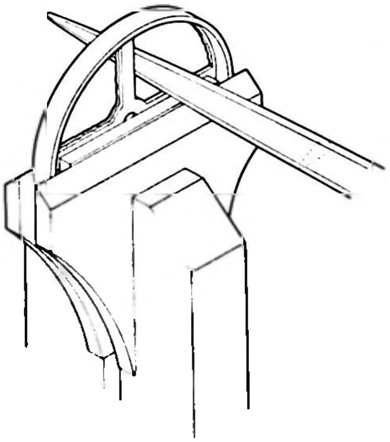
609 Locating the weight posts



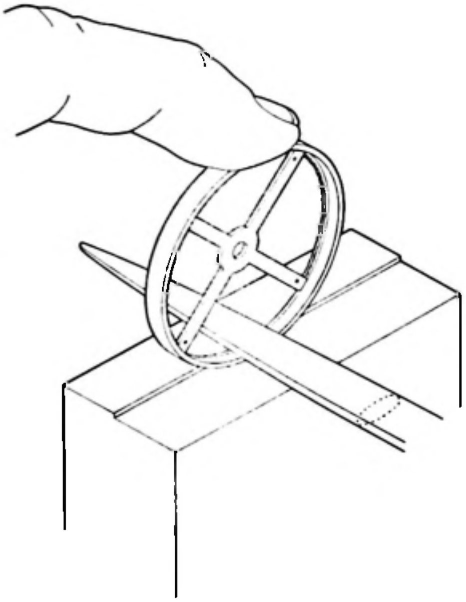
610 Piercing the crossings

Fit the parted balance with a light friction to the reduced end of the bar to ensure completely flat support for the final reduction in thickness. Scribe a circle for the hub diameter. Set the lathe tool below the centre by an amount equal to half the width the spokes are to be. Draw the point of the cutter across the surface to scribe the line of the spoke. Turn the work 180° and repeat to produce the full width of the spoke, as in Fig **609**. Repeat as necessary for extra spokes. Reset the tool exactly to the centre height and make marks, as shown in Fig **609**, for the weight posts, *A*. Finally cross these marks with the radial position of the posts, *B*.

Drill the balance to admit the piercing saw and cut out the spaces, as shown by the dashed line in Fig **610**, and complete by filing up to the lines. During the filing check the poise frequently and adjust by filing as the work proceeds. Hold the balance in the hand vice with a support cut from brass to fit within the rim, as in Fig **611**. To file the rim rest the balance against a ledge on a wood block. Hold down with one finger and allow the balance rim to find a level under the file, as in Fig **612**. Watch carefully both the shadow from the ridge and the filings trapped in the corner. When the file begins to disturb the dust resting on the rim, change to a smooth finishing file. Note the edge of the file ground to rest safely against the spoke to prevent scuffing. Make a chamfer at the intersection of the post marks and drill holes 0.4 mm diameter. Turn the posts with a taper of 0.01 mm from a blued-steel rod. Polish until the end will just enter the hole.

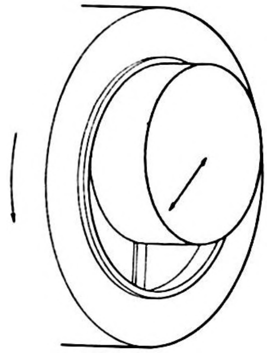


611 Filing the spokes

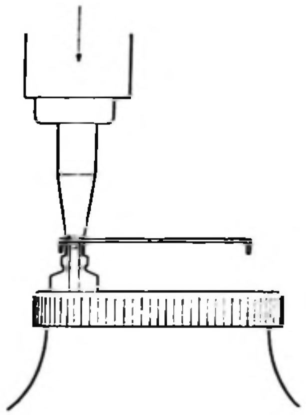


612 Filing the rim

Fit the balance on the bar as in 7, Fig **608**, and finish the underside with wood and oilstone paste to produce a circular grain. Make a recess in a wood or brass disc and fit in the balance to finish the upper side of the spokes with a wood disc, as shown in Fig **613**.



613 Finishing the spokes

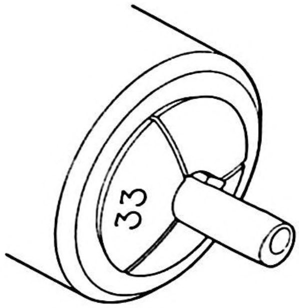


614 Fitting the weight posts

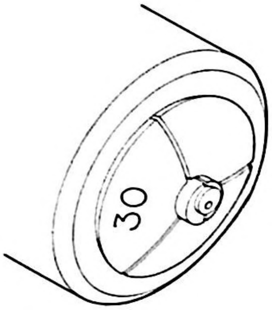
Polish the upper edge of the rim with diamantine on boxwood held flat on to the surface. Finally press in the posts, as in Fig **614**.

Adjusting Weights

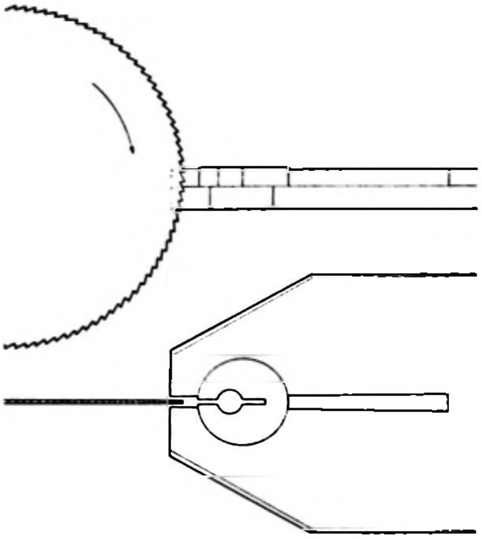
The weights are made from hard drawn, eighteen carat, gold rod drilled eccentrically and slotted to hold friction tight on the posts. The rod is most conveniently drilled by gripping in an eccentric bush. This can be made from brass to fit the lathe collets. Turn the brass to diameter to fit a collet of 3 mm bore. Put the bush into a collet of 3.3 mm bore and pack to one side with brass shim, as in Fig **615**. Centre with the graver and drill through to fit the diameter of the gold rod. Slit the end with a saw to allow the bush to flex and grip the rod. Cut the discs of the required thickness from the rod and while gripping them in the bush in a 3 mm collet drill the holes 0.4 mm diameter, as in Fig **616**. Hold the discs in the spring clamp, as in Fig **617**, and cut the slots. Note that the slot is cut from the short axis to allow a long slot with adequate strength at the flexing point.



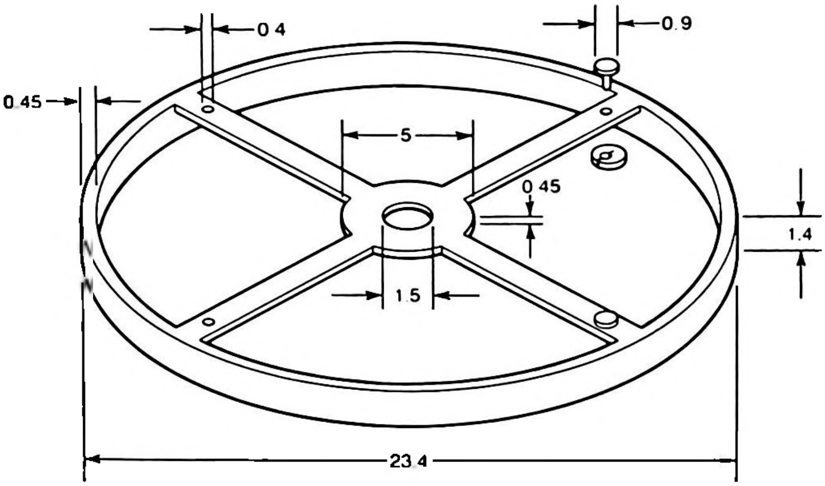
615 Drilling an eccentric hole



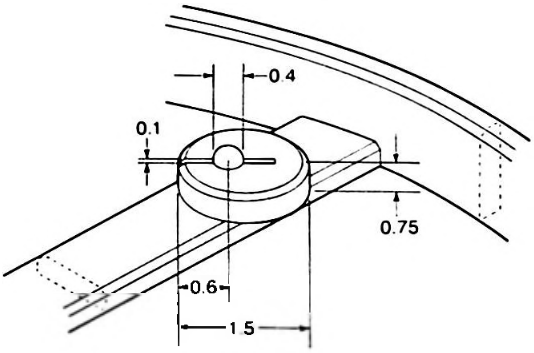
616 Drilling the weight holes



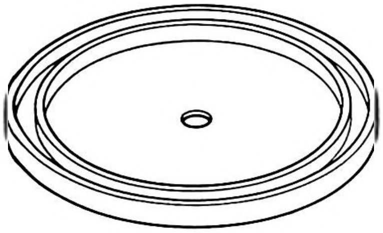
617 Slotting the weights



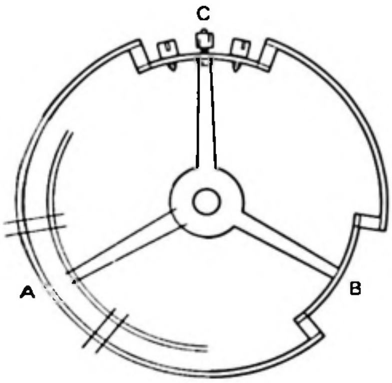
618 Dimensions of a Daniels balance



618a Detail of weight and post



619 Blank for recessed balance



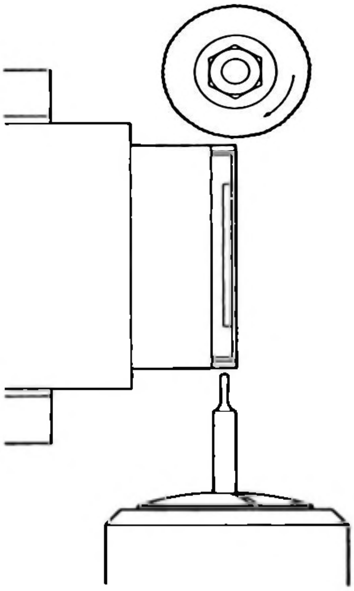
620 Stages of forming the recessed balance

Hold the disc on a turned arbor in the lathe and bevel the top corner with a burnishing file. Polish the top surface underhand with a tin polisher while the disc rests on a cork support. Close the slots by squeezing in the brass tweezers until the open ends meet. Press the finished weights on to the posts and check the balance for poise. Alter the weights until the assembly is in poise. The dimensions of a balance will depend upon the size of the watch. The dimensions given in Figs 618 and 618a would be suitable for a watch of the type illustrated in Plate IV.

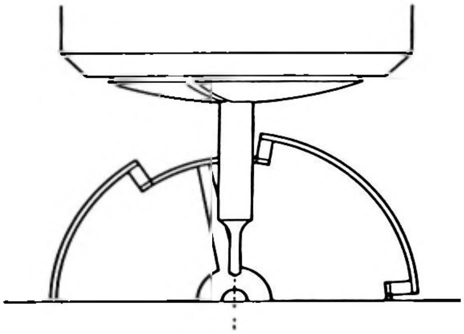
Recessed Screw Balance

For a balance with recessed screws, as illustrated in Plate II, two rings are needed for the rim. Turn the disc to the form shown in Fig 619. Mark out the spokes and recesses as shown in Fig 620 at *A*. Cut out and fit the screws as at *B* and *C*. The number of spokes is a matter of individual preference. The completed balance is illustrated in Plate VI.

Index the positions for the screw holes in the lathe, as in Fig 621. When the drilling quill is used in the lathe it must be set exactly to the centre height of the balance. If the holes are drilled with a drilling machine ensure that the drill is radial by lowering it towards the centre in front of the mark to be drilled, as in Fig 622.



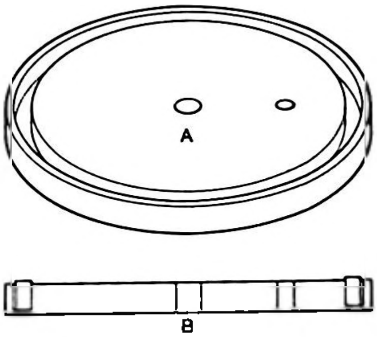
621 Indexing balance-screw holes in the lathe



622 Aligning the drill in the drilling machine

Bi-metallic Balances

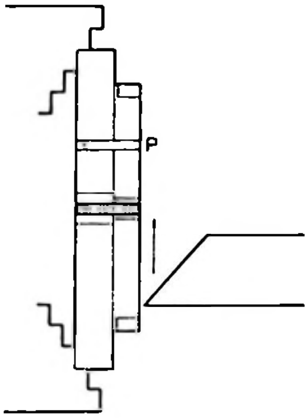
The bi-metallic compensation balance is made from steel with brass melted on to the outer surface of the rim. Turn the disc to the form shown in Fig **623**, *A*, and with an extra-deep outer groove to ensure the brass reaches the lower edge of the completed balance. Bore the centre hole true with the groove. After removing from the lathe drill the drive-peg hole. Turn a ring of yellow brass (non-free cutting) to fit the inner rim while leaving a small gap at the outer rim, as in Fig 623, *B*. Cover the surface of the groove and the brass ring with flux mixed to a thick paste with water. Put in the brass ring and heat until it melts and flows over the top of the groove.



623 Blank for a balance with bi-metallic rim

Success by this means is not certain. The weight of brass is insufficient to expel air that may be trapped in the groove. The gap at the outer surface will help by leaving space for the air to escape. The wet flux also helps by flowing over the surface as a layer of uniform thickness. Dry flux will certainly trap air. Trapped air will cause blow-holes and this will most likely occur in the corners of the groove. Turning the groove deeper than will eventually be required helps by increasing the weight of brass and by moving the corner further away from the final rim position. English chronometer makers stopped the centre hole with a soft iron rivet and completely immersed the disc in molten brass. This method would certainly avoid blow-holes but is not so convenient to use for a single balance.

Clean the back of the disc bright with a flat file or emery paper laid on a flat surface. Clean the centre hole bright with oilstone paste and wood. Mount the disc on a turned steel peg against a flat surface in the lathe, as shown in Fig **624**, with drive peg, *P*. Turn away the steel to expose the brass. Remove from the lathe and carefully

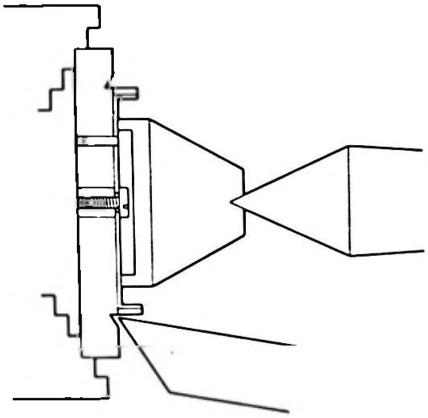


624 Mounting the blank in the lathe

hammer the brass to reduce its thickness by a half. Measure the thickness at several places to ensure the hammering is uniform.

Clean the back of the disc again so that it is flat and bright. Return it to the lathe and secure to the drive plate with cement. Face off with a cutter without top rake. Set the tool, as shown in Fig **624**, and cut with the back edge as the tool is advanced to the centre. By this means the disc will hold firm against the flat surface without risk of detaching. When the brass is exposed turn the disc over and again face off until the disc is to final thickness.

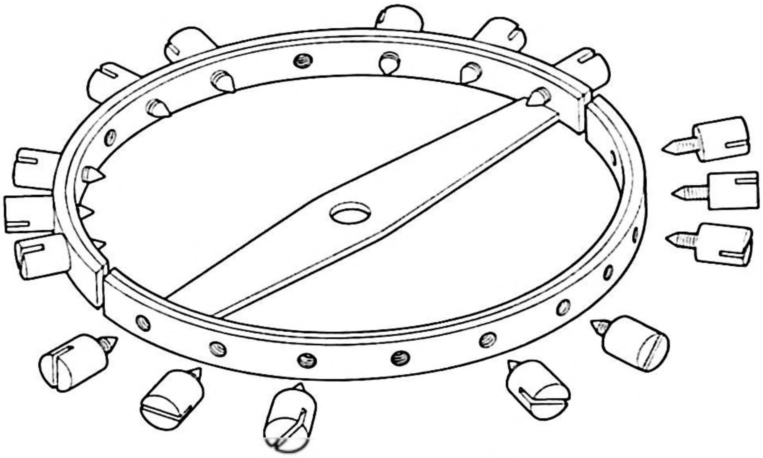
Turn out the centre leaving the bottom at the thickness required for the arms and the rim of steel at one-third the final required thickness of the rim. Finally turn the outer diameter leaving the brass twice the thickness of the steel inner rim. For the final cuts the balance is held more securely by a screw at the centre or clamped under the tailstock centre with a hollow cone as in Fig **625**. The balance can be returned to the driving plate as often as is necessary to adjust the ratio of steel to brass in the rim.



625 Securing the balance with the tailstock

If the brass is turned with a polished cutter it will need very little further polishing. Finish the steel as earlier described with oilstone paste and wood. Turn a small bevel at the corner and polish with a burnisher. Mark out the crossings and cut out the spaces.

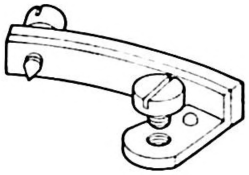
If movable screws are to be used for compensation adjustment the holes must be indexed in the lathe. Mount the balance against the flange of a turned bar in the lathe, as shown in Fig **621**. Note that the face of the bar is turned hollow to be quite sure that the balance is seated firmly up to the flange. Drill the holes with the drilling quill. Start above the centre of the spokes and drill the four quarter-holes for the rating screws. In the fixed quarter of each rim drill four further holes. These will be useful for weighting. In the free quarter of each rim drill holes for the temperature adjustment. Now polish the top surface of the rim with a tin polisher while the balance rests on a cork block. Turn frequently to avoid a grainy or lined finish. Finally cut the slots to free the rims. Note that these are cut at a chord of the rim to give support to the free end when held in the fingers for adjustment. The flange of the holding bar will prevent the rims flexing away from the cutter. The completed balance is shown in Fig 626 with screws made in the adjustable die shown in Fig 57.



626 Completed bi-metallic balance

Auxiliary Compensation

The mono-metallic balance of the watch illustrated in Plate IV is fitted with auxiliary compensation. The same methods of making are used as when making a compensation balance. Four pieces can be made at one time by making a balance with four spokes. Mark the spokes as explained earlier and drill one screw hole and one steady-pin hole in each spoke. Drill and cut the rim into four parts as described for Fig 621 but with radial cuts close up to the spokes. Only one hole is needed in the lamination, which is adjusted either by shortening in length or by increasing the weight of the screw. The completed auxiliary is shown in Fig 627.



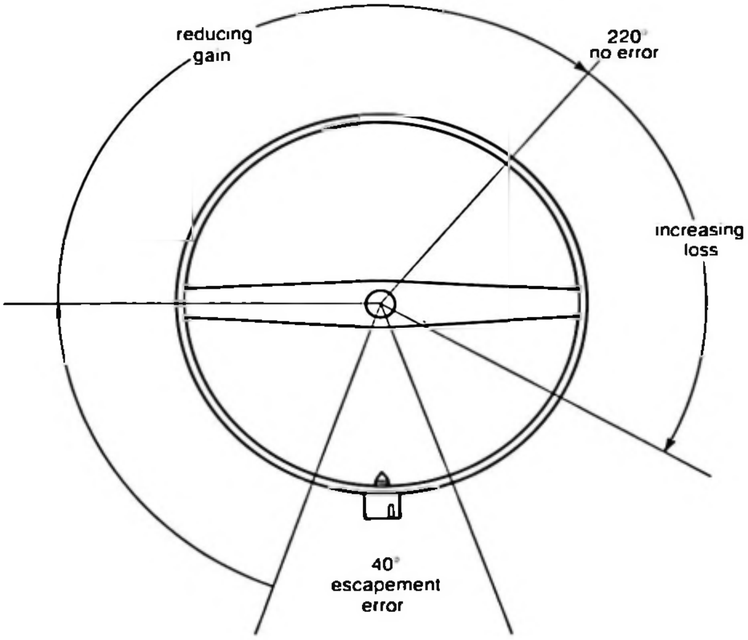
627 Auxiliary compensation attachment

Adjusting the Balance

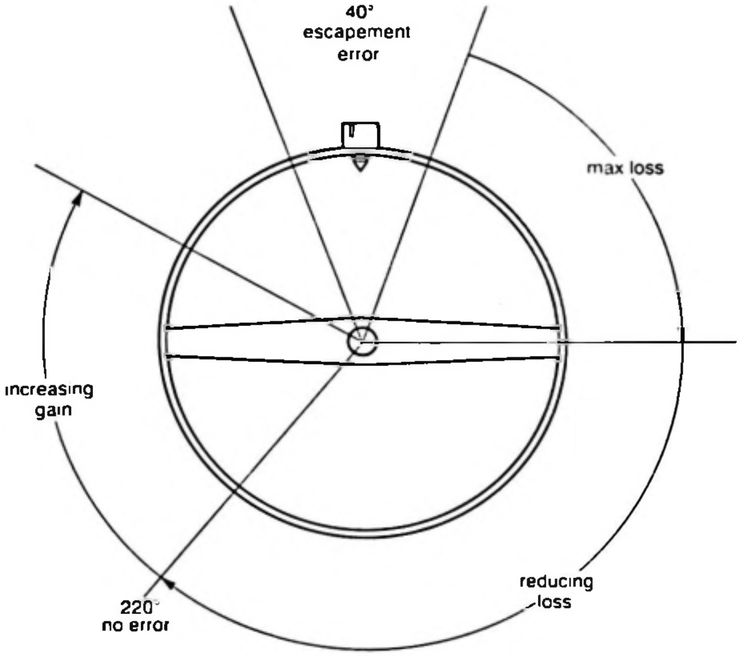
When the adjustments for temperature and isochronism are completed the balance must be finally adjusted for poise to make the edge position rates equal. To avoid complication the quarter weights or screws should be equal in mass and the balance brought to poise by the addition or subtraction of additional weights.

The period of vibration of an unpoised balance varies with change of balance amplitude and change in position of the centre of gravity. The effect of this is shown in Fig 628 where a weight added below the centre of motion causes a gain in rate that diminishes up to 220° after which, with increasing arc, it causes an increasing loss. The reverse happens when the balance is turned through 180° so that the weight is above the centre of motion to cause a loss below 220° and a gain after 220°, as shown in Fig 628a.

If the balance arc of vibration was constant at 220°, poise errors would not occur. This principle was followed by English makers who set the arc of a heavy balance to 220° and held it constant with a fusee. The watch illustrated in Plate II employs a *remontoir* to achieve the same result. Breguet's *tourbillon* carriage is the most


reducing gain
220° no error
increasing loss
40° escapement error

628 Effect of added weight below balance axis


40° escapement error
max loss
increasing gain
220° no error
reducing loss

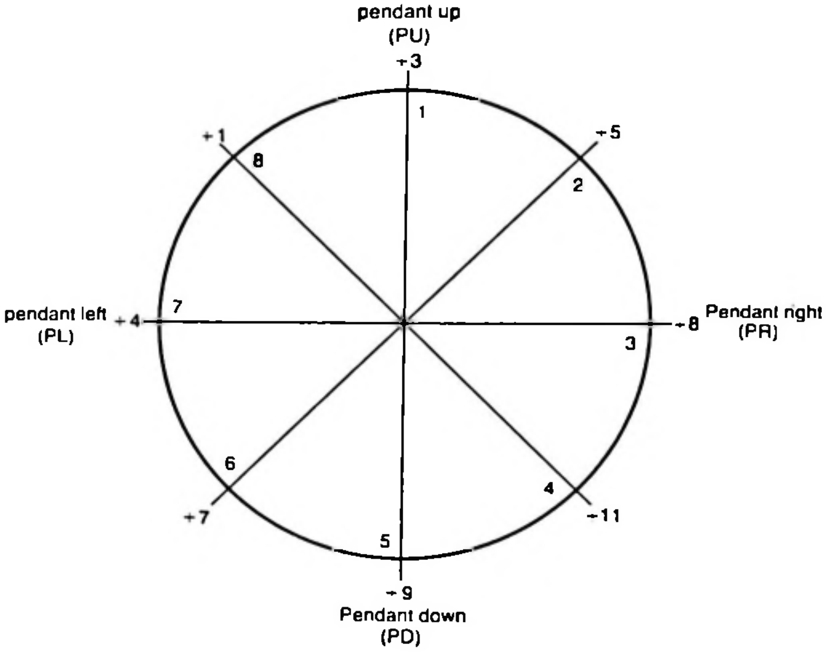
628a Effect of added weight above balance axis successful means of smoothing errors of poise. This averages all the poise errors arising from change of position to produce a uniform daily rate.

In the initial stages the adjusted position rates, within five seconds per day, can be taken from the timing machine. For finer adjustment the watch must be run for twenty-four-hour periods. The tests can be made at a constant temperature but both temperature and isochronal adjustment must be completed before the edge position tests.

Locating the Error

Check the rates at 130° of semi-arc with the watch vertical on the microphone. Note the errors at the eight positions of 45° intervals of vertical. Make the correction according to the mean error of the watch. In Fig 629 the rates for the eight positions are noted and the mean error is fast. Correct the poise and mean error by adding weight to make the balance heavier above the centre of motion with the pendant at position 4. This will slow all the positions but will have the greatest effect at position 4. The error will probably fall between two screws or weights of the balance so that it will be necessary to divide added weight by proportion according to the positions of attachment.

The amount and position can be quickly determined by sticking the weights to the rim at the attachment positions with a smear of oil. When the balance is within five seconds per day in the three positions 1, 3 and 7 secure the weights and start the twenty-four-hour tests. Note that the errors at positions 1 and 8 are too small to be accurate for a short run but position 4 is large enough to need certain correction. For the twenty-four-hour tests the watch is fully wound and the errors of poise remaining will be reversed.



629 Noting the rates for positions

Whatever the errors may be it is possible, in theory, to equalize them by a single adjustment at one point in the balance rim. In fact it will be necessary to make a series of small corrections according to the results of the daily tests. It is not necessary to check the rate of *PD* (position 5, Fig 629) once the initial tests have shown that no magnified error arises as a result of a mechanical fault in the escapement.

Slow Vertical Rates

It will be found that the rates for the vertical positions are slower than the rates for the horizontal positions when conventional balance staff pivots and jewel bearings are used. This is due to the increase in friction of the balance pivots when the watch is in vertical positions. The error can be corrected throughout the range of the variable balance amplitude only by correction to the balance suspension.

If necessary the *PU* position can be equalized with the horizontal position by alteration to the poise of the balance. This will put the loss of the *PU* position into the *PD* position which may also include a loss arising from the point of attachment of the balance spring to the collet. This combination of errors could amount to about four seconds per day in the *PD* position, the amount depending on the form of the balance pivots and weight of the balance spring.

Unless the watch is kept quite upright in the pocket some of the correction will be lost and the rate will appear erratic. It is better to adjust the vertical rates to a common error against the horizontal rate and allow a correction for vertical use.

Balance Springs

The earliest balance springs were fitted to watches in the 1670s but were not common until after 1680. They took the form of a steel spiral of one and a half to two turns. The inner end was pinned to a brass collet fitted to the balance axis while the outer end was pinned to a stud fitted to the watch plate. The vibration period of the balance could be regulated by sliding curb pins, in a movable bracket along the outer coil, effectively to lengthen or shorten the active length.

The only escapement available for watches in the seventeenth century was the verge. Its notoriously bad timekeeping was improved dramatically by the application of the spring. A good-quality verge with spring will run to within three minutes per day. Without a spring it may vary by as much as twenty minutes per day. With the introduction of new escapements in the eighteenth century the rates of timekeepers improved so that variations in rate with change of balance amplitude of vibration could be measured. The variation in the rate is caused partly by the escapement and partly by the spring. The amount attributable to each depends on the type of escapement used and the form and dimensions of the spring.

It will be remembered that the escaping angle is a proportion of the total arc of the balance. As the balance amplitude falls, so the escaping angle represents a larger proportion of the total arc. Since the escaping angle retards the period of vibration then a diminution of total arc will cause an increase in vibration period. A comparison between the lever and the chronometer escapements shows that they have different errors and the same spring will not suit both. These are chosen as the most common forms of single impulse and double impulse escapements.

Chronometer Escapement Error

The unlocking of the chronometer occurs after the centre line of the escapement which is the quiescent point of the balance spring. This will represent a loss of energy which will cause a gain in rate. The impulse will also occur after the centre line and this will cause a loss in rate. The unlocking is accomplished at a very small radius of the balance axis and the energy loss is small. As a consequence the required energy input is small and the average error arising from their combined actions is small.

The second vibration of the oscillation is virtually without interference to the balance and the natural period of the spring will determine the period of the vibration. If the arc of vibration is 270°, giving a total arc of 540° per oscillation, then for an escaping angle of 35° the balance will be free to swing in its natural period for 505°. A reduction in amplitude of vibration of 90°, leaving a total arc of 360° per oscillation, will produce a loss in rate of about eight seconds in twenty-four hours.

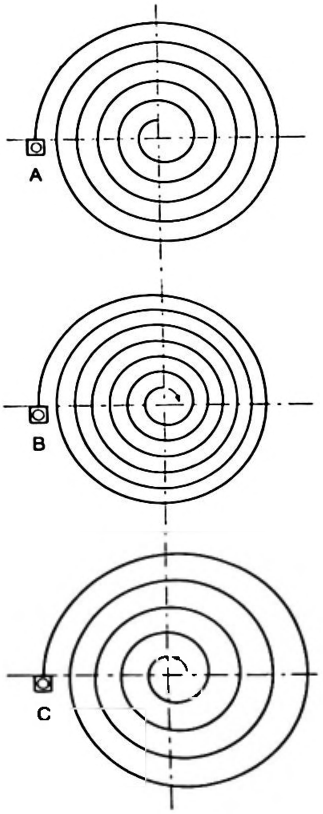
Lever Escapement Error

For the lever escapement the radius of unlocking at the balance axis is equal to the radius of impulse. This subtracts a greater energy from the balance. In addition the unlocking is heavier, due to the draw angle, and occurs before the line of centres. All these factors combine to produce a loss. Only a small part of the impulse is delivered before the centre line to cause a gain. The main impulse is given after and causes a loss. In addition, the action occurs at each vibration so that the losses are doubled. For an escaping angle of 32°, including the run to the banking, and a total arc of 540°, the balance will be free for 476°. A reduction in total arc leaving 360° per oscillation will produce a loss in rate of about twenty seconds per day.

Early makers of precision watches avoided the worst effects of escapement error by using a fusee to equalize the force of the mainspring during the twenty-four-hour period. Provided the watch is kept in the horizontal position the arc with the fusee will remain constant. The watches were fitted with heavy bi-metallic, cut-rim balances which contracted with the reduced centrifugal force of short arcs which occurred only in the edge positions. It was the practice to discover the short arc rate by taking the mean rate of two opposite edge positions. With experience the best weight and proportions were found so that the edge error could be exactly and permanently corrected.

The best watches employed meticulously formed outer and inner terminal curves so that the spring would not influence the rate with change of balance amplitude. By an understanding of the characteristics of the spring their makers were able to avoid its influence on their form of adjustment for isochronism. With modern, monometallic balances different and more complex techniques are needed to exploit fully the potential isochronal correction available in the spring.

It may be thought that the ease with which the escapement can be made isochronous when a cut balance is used would suggest that, at least with individually made watches when expense is of no importance, they would be better than the uncut variety. But it is a fact that the best rates of uncut balances with temperature corrected springs are more stable in the long term than the rates of bimetallic, cut balances.



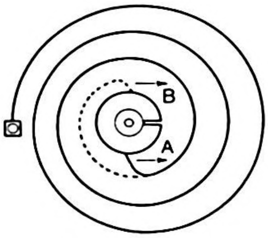
630 Eccentric displacement of the flat spiral spring
A Spring relaxed
B Spring wound through 360°
C Spring unwound through 360°

Influence of the Balance Spring

John Arnold was the first maker of precision pocket watches and it was he who discovered the method of manipulating the balance spring to equalize the rates for different balance amplitudes. He used a helical spring but the principles he discovered are equally applicable to the spiral spring.

Fig 630 at *A* shows a spiral spring at rest with the coils relaxed and equally spaced; *B* shows the same spring wound through 360°; and at *C* the spring unwound 360°. Because the outer end of the spiral is at a fixed radius from the centre the contraction and expansion are eccentric.

If the spiral terminates at the centre of motion the energy in the spring will be proportional to the angle of winding less only the extra friction of the pivots due to the side thrust of the coils. But when pinned to a collet the termination of the spring is at a fixed radius from the centre of motion. The eccentric action will exert a variable pressure at this radius to affect the natural period of the spring. The magnitude and direction of the pressure will depend upon the number of turns in the spiral, the relative orientation of the inner and outer pinning points and the angle of turning of the collet. In Fig 631 the thrust on the collet is pulling in the direction of unwinding at arrow *A*. Adding an extra half turn to the spring or unwinding through an extra half turn will apply the pull to the opposite side of the collet at arrow *B* and in the reverse direction.



631 Effect of the eccentric spring on the balance collet

Influence of Balance Amplitude

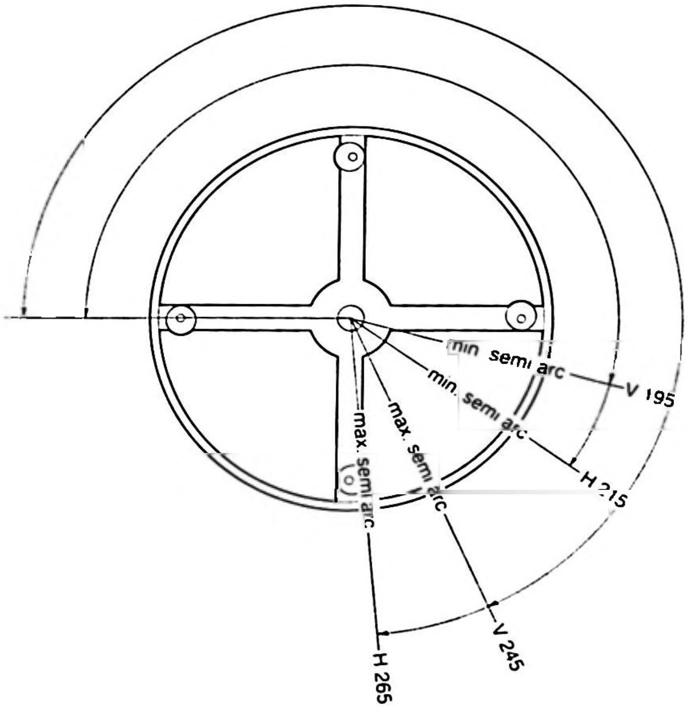
The balance will have its maximum arc when horizontal with the watch fully wound. The minimum arc will occur with the watch vertical after twenty-four hours' running. The extent of the arc is a matter for the maker but there are certain limits that should not be exceeded if difficulty in regulating is to be avoided.

Below 180° of semi-arc the escapement error increases rapidly, as also does the effect of poise errors in the balance. Above 260° the poise errors are again increased but in the opposite sign. The ideal arc would be 220° for at this amplitude the poise errors do not influence the rate. The arc will fall during a twenty-four-hour period by 50° to 60°. To this must be added the difference in arc between the horizontal and vertical positions. When horizontal the weight of the balance is taken on the domed end of the pivot resting on the endstone. This is virtually a point contact with very little friction. In the vertical position the friction is generated at the radius of the pivot and is much higher. As a consequence the balance arc will reduce by an amount dependent on the weight of the balance and the diameter of the pivots.

With the watches illustrated in the Colour Plates the reduction in arc is small as a result of having large diameter, light balances and small diameter pivots. A reduction of 20° of arc occurs between the horizontal and vertical positions. Taking an average figure of 50° reduction during the twenty-four-hour run and the 20° between the vertical and horizontal, there are 70° to be considered between maximum and minimum arcs. The ideal arc of 220° is of no consequence in the horizontal position which is not affected by poise errors.

If, as in Fig **632**, the maximum semi-arc in the vertical with the watch fully wound is set at 245°, then the minimum semi-arc after twenty-four hours will be 195°. These limits will almost contain any positional errors which, if they show at all, will only be apparent at the beginning and end of the twenty-four-hour period.

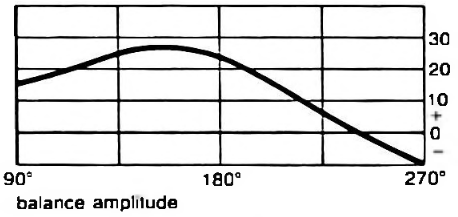
The 70° of variation between the long and short arcs will cause a loss of rate in the short arcs of about fifteen seconds in twenty-four hours for a lever escapement and about six seconds for a chronometer escapement. The precise amount will depend on the quality of construction of the escapement and the type of spring material used.



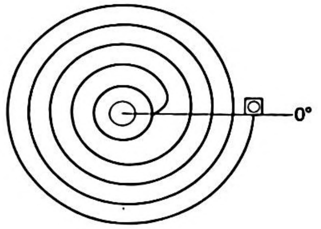
632 Maximum and minimum balance amplitudes

Lossier's Rules for the Point of Attachment

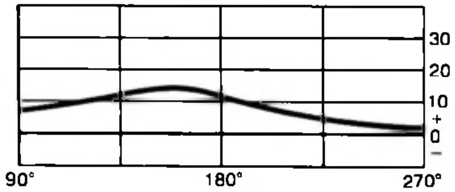
The correction can only be made by trial of the spring in the watch but the work will be simplified if Lossier's figures for the rates due to the pinning points are considered. Figs **633a** to **d** show in graph form the results of his observations expressed in seconds per day gaining or losing for change of balance arc with the appropriate point of attachment to the collet.



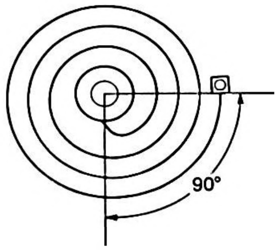
633a Rate for a spring pinned at whole turns



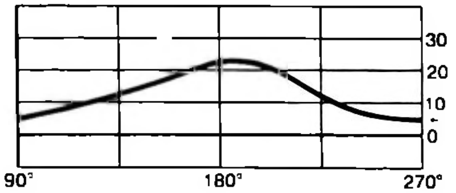
633a Spring pinned at whole turns



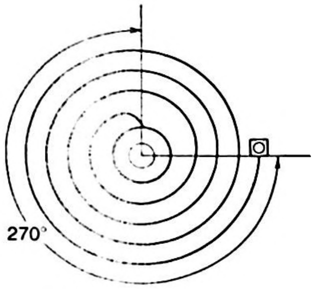
633b Rate for a spring pinned at extra 90°



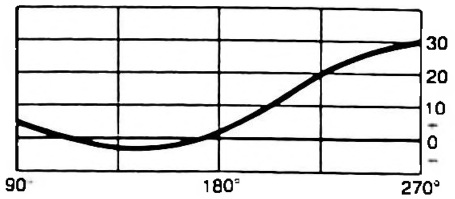
633b Spring pinned at extra 90°



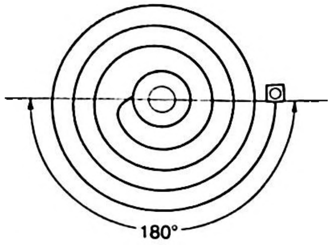
633c Rate for a spring pinned at extra 270°



633c Spring pinned at extra 270°



633d Rate for spring pinned at extra 180°



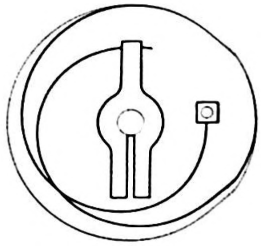
633d Spring pinned at extra 180°

In Fig 633a the spring is pinned to the collet at full turns, so that inner and outer pinning points are on the same radial line. This results in a gain in rate from 90° to 160°, followed by a loss in rate from 160° to 270°. The rate below 160° is not important because the balance arc will not fall to this figure during the twenty-four-hour run. The thirty-five seconds change in rate between 160° and 270° will represent a gain as the arc falls during the twenty-four-hour run.

If the spring is for a lever escapement with a loss of fifteen seconds between the chosen arcs of 240° and 195° maximum and minimum, the watch will gain approximately five seconds in the short arcs. Pinning the spring to the collet at full turns will overcorrect the escapement error. Such a spring would be quite unsuited to a chronometer escapement with a short arc loss of only six seconds. For this escapement the pinning point at 90° to the stud would be better, as shown in Fig 633b. The gain in the spring between 250° and 195° will almost match the smaller escapement error. The figures given above for the gains and losses can only be approximate and will depend on the construction of the watch and the characteristics of the spring material.

The error for both escapements applies to the use of a rigid balance. If a cut compensation balance is used the rate will be affected by the centrifugal forces acting on the rim to increase the radius of gyration in the long arcs. With a very thin rim with heavy weights, as used in early chronometers, the rate could be slow in the long arcs. In such a case Fig 633c, pinned in at 270° as practised by John Arnold, would be suitable. His watches have a long arc of approximately 180° and a short arc, in the vertical position, of approximately 150°.

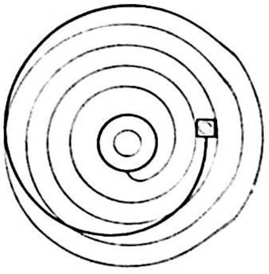
Altering the direction of thrust of the spring by small changes in the pinning point will enable small changes in rate to be made so that the long and short arc rates can be equalized. This method is used in factories to establish the pattern of mass production but is not convenient for a maker of individual watches.

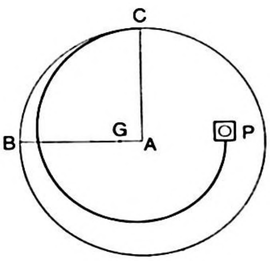

634 Arnold's terminal curves

Convenience of the Terminal Curve

For individual watches it is better to use a terminal curve, as devised by Arnold for the helical spring and applied by Breguet to the spiral spring. Fig 634 is a plan view of Arnold's helical spring with upper and lower terminal curves. Fig 635 is Breguet's application in which the curve is raised above the spiral of the spring. By changing the radii and length of the curve the spring can be made to work eccentrically in any chosen direction.

When shaped to a formula, calculated by Edouard Phillips in 1858, the spiral spring works perfectly concentrically so that the long and short arcs are isochronous. Such a spring is of little use to the watchmaker who needs a spring that is non-isochronous with an error equal to, but opposite in effect to, the escapement error of his watch. Arnold understood this perfectly well nearly eighty years earlier and a study of his work reveals the extent and direction of the required eccentricity to achieve a practical isochronism.


635 Breguet's application of the terminal curve to a spiral spring



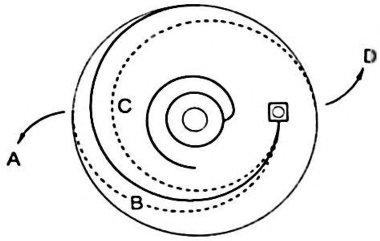
636 Phillips' terminal curve

Fig **636** shows a form of curve, shaped to the formula of Edouard Phillips. *G* is the centre of gravity of the curve situated on the line *AB* at 90° to *AC* and at a distance from the centre of the spring *A* equal to $\frac{AC^2}{L}$. *L* is the length of the curve measured from *C* to the pinning point *P*. Formed in this way the spring would work concentrically and, if fitted to a watch, would reveal the extent of the escapement error for any chosen long or short arcs. This will not be an exact figure because the inner end of the spring is pinned at a fixed, finite radius and so can work eccentrically. The isochronal error from this source is very small and, for all practical purposes the error revealed will be the escapement error.

It is possible to apply an inner terminal curve to allow the spring to expand and contract concentrically at the centre. But due to the extreme difficulty of forming so small a curve accurately the results are uncertain.

Adjusting the Terminal Curve

It is not strictly necessary to consider the relative points of attachment of the ends of the spring because the curve can be made to work eccentrically in any direction. However, the greatest variation in the eccentricity for the smallest change in shape of the curve will occur opposite the outer pinning point.



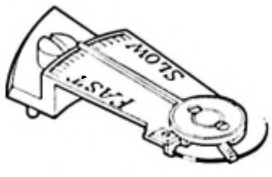
637 Altering the shape of the terminal curve

In Fig **637** the pinning points lie on the same radial line with the spring working concentrically. To quicken the short arcs greater eccentricity is required in the direction of the arrow *A*. Reshaping the curve towards the dashed line *B* will make the curve more flexible in the required direction. If the opposite effect is needed the curve must be brought nearer the centre to increase the flexibility at *D*. This is shown by the dashed line *C*. It will not produce so great a change as *B* unless the radius of the stud is reduced. Since it is inevitable that the watch will lose in the short arcs it is better initially to observe the points of attachment for the appropriate escapement.

The spring collet must be carefully centred above the balance jewel hole after each alteration to the shape of the curve. When making an alteration observe closely the radial position of the stud relative to the coils of the spring, and set the curve to maintain this position. Any centring that may then be required can be done by bending the spring close to the stud.

An error of centring after manipulation of the curve will produce a change in daily rate and, due to the change in pivot friction, small changes in the positional rates especially in the short arcs.

Curb Regulators



638 Curb regulator

It is common practice now to fit watches with a regulator, as shown in Fig 638. The spring passes between two pins and its length is effectively changed to alter the timekeeping by moving the regulator. The practical effect of moving the pins is to change the position of the inner and outer points of attachment, so that the adjustment for isochronism is disturbed. At one time the regulator was a cheap and ready means of achieving a rough isochronism by adjusting the play of the spring between the pins. If the spring is biased a little towards the inner pin it will rest upon it increasingly as the balance amplitude decreases and the short arcs will be quickened. The results are not sufficiently precise for a precision timekeeper and if the regulator is moved the effect is changed.

Regulators are a convenience to makers of mass-produced watches but are not necessary in good-quality, hand-finished watches. Such watches are brought to time by adjusting the balance, and subsequent regulation of the rate is not required.

Checking the Rate

The rates for the long and short arcs should be taken with the watch in the horizontal position. This will avoid the inclusion in the rates of errors that do not arise from imperfect adjustment of the spring. Ideally the rates are taken at twenty-four-hour intervals but it is difficult to maintain a constant high or low balance arc throughout this period. If a slow-running timing machine is available the rates can be taken for ten-minute periods at chosen high and low amplitudes. Alternatively the rates can be taken at twelve-hour intervals with the mainspring power appropriately replenished at two-hour intervals. It is inconvenient to change the mainsprings for each test and they would still need winding at eight-hour intervals to maintain the arc for twenty-four hours at the required value.

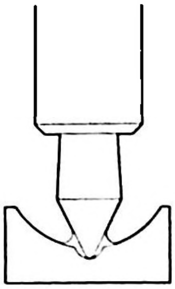
Due to the increased pivot friction the rates in the vertical positions will be slower than the horizontal rate. The difference between the rates can be found by taking the average of two opposite edge verticals for comparison with the horizontal rates. These rates will be influenced by the diameter of the balance pivots and the angular velocity of the balance. The angular velocity of the balance is determined by the amplitude and period of vibration. Small diameter pivots will reduce the rubbing friction and high balance velocity will reduce the period of static friction at the end of the vibration when the balance is momentarily stationary.

For an average sized pocket watch of 18,000 vibrations per hour (five per second) the loss in the vertical positions is about six seconds in twenty-four hours at 180° of semi-arc. This will reduce to three seconds when the arc is raised to 270°. Increasing the number of vibrations to 21,600 will reduce the error to two seconds.

Correcting the Vertical Rate

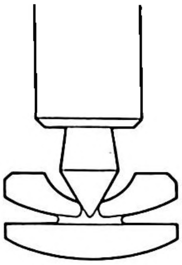
The vertical rates can be made faster by overcorrecting the escapement error but the horizontal rate in the short arc will then be fast by the same amount that the vertical rate was slow. A compromise would produce an acceptable result but the watch must be regulated to go fast at the beginning of the day by half the total error.

The vertical and horizontal rates can be equalized at all balance amplitudes if the friction at the balance pivots is kept constant with change of position. Breguet did this in 1787 by using pointed pivots running in blind holes, as shown in Fig 639. He protected the delicate points by fitting the jewels into flexible mountings. With



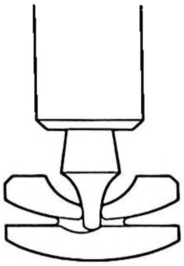
639 Conical pivot and blind hole

this form of suspension the end-shake necessary to give freedom to the pivots is reflected in an equal amount of side-shake. If this is kept to a minimum it will not have an adverse effect on the rate. The principal disadvantage is the smallness of the oil reservoir and the large radius of adhesion of the oil. With change of temperature the viscosity of the oil will vary and noticeably affect the daily rate.



640 Pivot with increased friction

The watch illustrated in Plate V has pointed pivots supported in conventional jewel holes with endstones. Fig **640** shows the arrangement in which the cone of the pivot is resting in the hole with the point clear of the endstone. The oil reservoir remains the same as for a conventional pivot. With this system the friction in the horizontal position is higher than the friction in the vertical position and, as a consequence, the vertical rates are faster. As a means of equalizing the horizontal and vertical rates it is not successful but its variation is no greater than for a conventional pivot. It has the merit of being very strong and resistant to accidental damage. In addition the gain in the verticals is more acceptable than the loss caused by the conventional pivot.



641 Pivot with increased friction

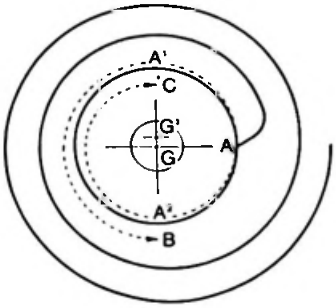
The watch illustrated in Plate IV is fitted with endstones with hollows cut into their faces to bias the pivot against the side of the jewel hole. The arrangement is shown in Figs **641** and **428a** where the pivot rests on one side of the hollow and is urged by the weight of the balance, in the direction of the arrow, to press to the side of the hole. By this means the rates for the horizontal and vertical positions can be equalized once the correct form of the hollow is established by trial.

If a fusee or some other form of constant force mechanism is used the horizontal arcs will remain constant and the vertical short arcs can be equalized by manipulation of the terminal curve. This system is used in Plate II which employs a *remontoir* released at fifteen-second intervals to maintain the horizontal amplitude.

Point of Attachment Poise Errors

A terminal curve formed exactly to Phillips' conditions for isochronism will allow the outer coils of the spring to expand and contract uniformly. The inner coils cannot do so because they are attached to the collet at a fixed radius. This inevitably introduces a variable error of poise as the spring expands and contracts. The greater the balance arc the greater will be the shift of the error to and from the centre of motion.

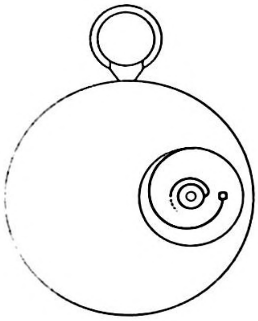
In Fig **642** the spiral is at rest at *C* and may be considered to be poised with the centre of gravity at centre *G*. When the spring is wound it will contract and point of attachment *A* should contract to radius *C*. It cannot do so and remains at radius A^1 and the centre of gravity of the spiral is raised to G^1. In unwinding *A* should expand to radius *B* but remains at A^2 and again the centre of gravity is raised to G^1.



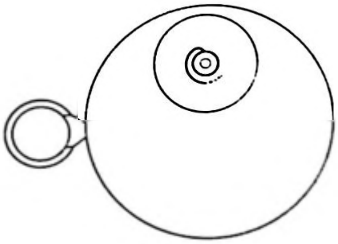
642 Shifting centre of gravity with conventional collet

This has the effect of putting the spring out of poise. As shown in Fig **642** the centre of gravity will be above the centre of motion to cause a loss in rate. As the balance arc increases the centre of gravity will turn to one side where it does not affect the rate. At high amplitudes the centre of gravity is below the centre of motion and will cause a gain in rate. The gain will be greater than the loss because expansion and contraction increase with the increase in arc.

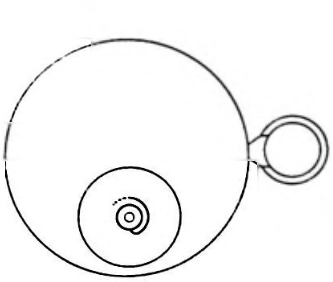
The size of the error will depend upon the weight of the spring and the amplitude of balance arc. Short springs are better than long springs which need thicker wire to reach the same vibration period and are therefore heavier. Early temperature compensated springs were heavy and could produce a noticeable error. To suppress any possible losing error it is usually advocated that the spring be turned so that the centre of gravity is below the balance axis when the watch is in its most usual position. For a pocket watch this will be pendant-up as carried in the pocket. Fig **643a** shows the position with the spring pinned to the collet to bring the centre of gravity below the balance axis in the long arcs. This is shown also in Fig **642**. Note that in Fig **643a** the points of attachment lie on the same radial line and so the condition for ease of isochronal adjustment is also satisfied. The positions shown in Figs **643b** and **c** will not be affected by the pinning point and any losses will be confined to **643d**, pendant-down, in which position a pocket-watch is not used. This system is convenient for mass-produced watches which do not receive any adjustment other than regulation for daily rate.



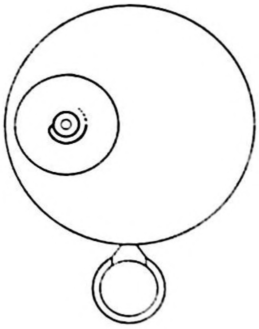
643a CG above static collet



643b CG to left of static collet



643c CG to right of static collet



643d CG below static collet

For adjusted watches the pinning point is not so important. The error will show as a variable change in rate dependent on the balance amplitude. This is the same effect as a small lack of poise in the balance which also changes magnitude with change of balance arc. With adjustment to the balance the effect can be counteracted by dividing the error in twenty-four hours between two opposite positions.

Influence of Collet Diameter

The greater the collet diameter the greater is the radius of the poise error which will increase as the square of the radius of gyration. But the magnitude of the error is affected by the ratio of collet diameter to balance diameter. For small watches the collet diameter cannot be reduced in proportion to the reduction in balance diameter. As a consequence the error for small watches is greater than the error for larger watches. The relatively larger diameter pivots of the smaller watch cause the balance amplitude to fall further during the day's run than would be the case with the larger watch. This causes a noticeable change in the error manifest as a drift in rate during the twenty-four-hour period.

In such a case the watch may be adjusted to show zero error in the edge positions for a twenty-four-hour period while, at the twelve hour interval the rate would be some two seconds in error. To avoid such errors modern small watches are fitted with flat, spiral springs cemented into very small collets. The flat spiral allows correction for escapement error which would not be available if an overcoil spring were used with a small collet.

Influence of the Outer Coils

The eccentric expansion and contraction of the outer coils of the flat spring occurs opposite the outer point of attachment. This will cause the centre of gravity of the spring to oscillate in sympathy with the balance vibrations. Because this oscillation is radial it does not affect the vibration period of the vertical positions and has no measurable effect on the rate. There must obviously be a small angular displacement but this is always in the same vector of the radial and angular displacement and is too small to have influence.

Making the Balance Springs

For the modern mono-metallic balance, the balance spring is formed from an alloyed material which is virtually unaffected by temperature changes. Springs made from steel require a bi-metallic balance to correct the effects of change of temperature on the balance spring. Steel springs are no longer used in watches and as a result the drawn steel wire for their manufacture is virtually unobtainable.

When alloy balance springs were newly introduced in the early twentieth century they were not very successful when compared with the best performances of watches with steel springs. Changes in the materials and the processes of their manufacture have improved the springs so that they have superseded the old steel springs.

Whenever possible the springs should be purchased ready for fitting. There are several specialist makers of springs whose products can be purchased from material shops. The heat treatment required to set the springs to shape and achieve maximum elasticity must be most carefully controlled. It is dependent upon the constituents of the alloy and the amount of rolling and drawing required to form the wire. The manufacturers of the alloy can supply information on suitable heat treatment.

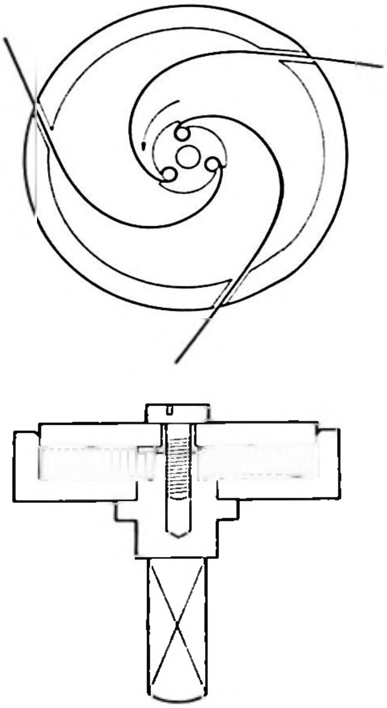
The coils of the spiral spring are wound three at a time into the brass box, shown in Fig 644, to ensure adequate spacing. The arbor is turned by a pin vice attached to the square. The lid is kept lightly pressed on to the wire by finger pressure to cause sufficient friction to ensure even winding. When the box is full the lid is pressed into contact with the wire by the screw threaded into the arbor.

The heat treatment should be conducted in a temperature-controlled furnace with an oxygen-free atmosphere. After heat treatment remove the lid and push out the arbor to release the springs which are ready for use.

Steel springs are formed in the same way but need to be plunged at red heat into water in order to set and harden the wire. The method of tempering used by earlier spring makers was by immersion in boiling oil.

If the hardening and tempering is done in an oxygen-free atmosphere the springs will remain bright and can be blued on a flat brass plate in the furnace or held over a spirit lamp, under a glass cover, to preserve an even temperature. If an oxygen-free furnace is not used the springs will become discoloured during the heating.

The method usually recommended for polishing spiral springs is to pull them into cones and laboriously apply polishing paste by brush and peg-wood. It would be better to avoid the work by using a modern furnace.



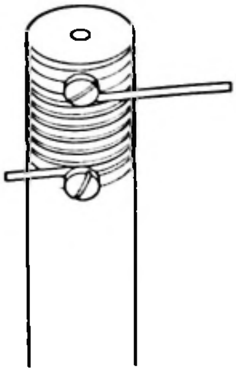
644 Box for spiral springs

Helical Springs

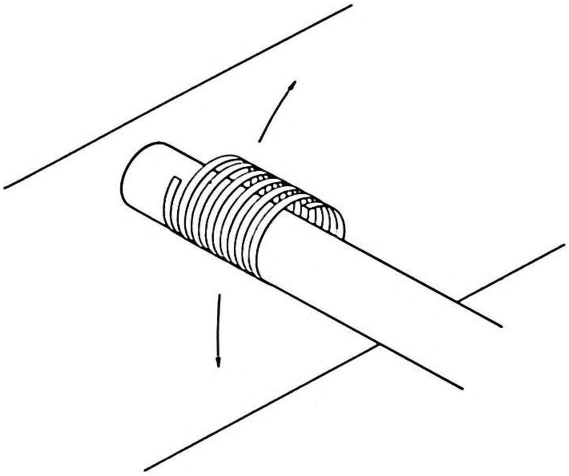
Helical springs are simpler to make and polish. The wire is wound on to a hollow former cut with a thread of suitable pitch and width. The ends of the wire are secured with screws, as shown in Fig 645. Most helical springs are wound clockwise from the stud and so the screws will need left-hand threads to pull the wire tight on to the former.

After the heat treatment the springs can be polished inside with a smooth, wood rod and polishing paste while supported on blotting paper. The outer surface and edges are polished with a brush and polishing paste while supported on a rod, as in Figs 646 and 647. Because the helical spring is easily polished without risk of distortion an oxygen-free furnace is not essential although it is to be preferred.

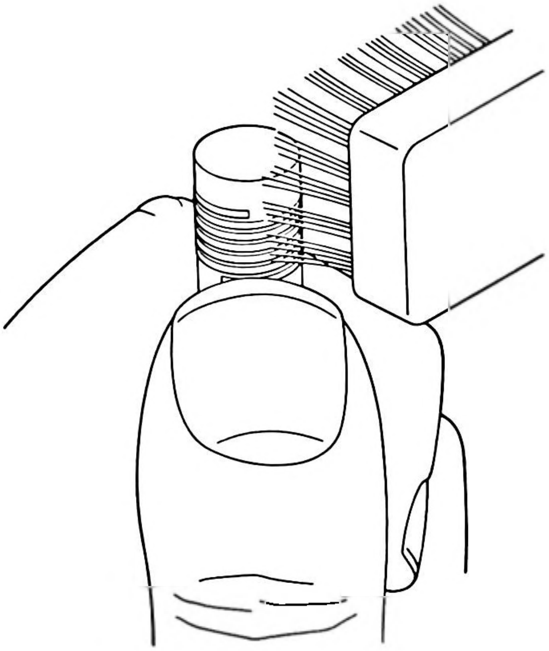
The steel spring can be raised to red heat with a blow torch but the wire must be protected from the flame by a thin outer covering tube. This can be formed of copper sheet wrapped once around the steel former and secured with binding wire. Rotate the former in



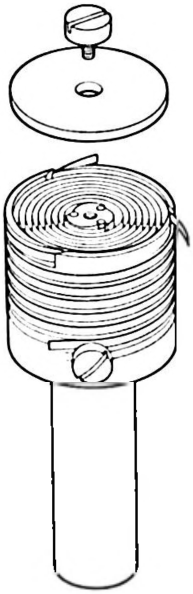
645 Former for helical springs



646 Polishing the interior of the helical spring



647 Polishing the exterior of the spiral spring



648 Box for duo-in-uno spring

the flame until the copper is bright red. Quench by dropping vertically into water.

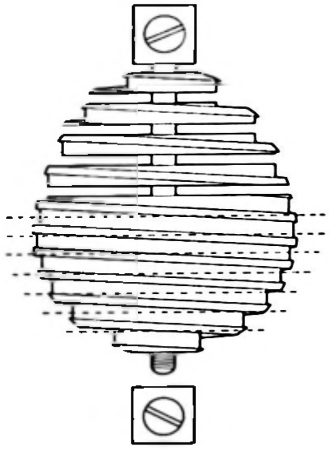
Remove the cover and check the tightness of the securing screws. Temper in boiling oil before removing from the former. Finally polish and oxidize to a blue colour.

Duo-in-Uno

Two other forms of spring may be worth describing for historical reasons only. These are the duo-in-uno and the spherical. The duo-in-uno is a spiral spring formed at the base of a helical spring. The box for forming the spiral is raised in the form of a tube for forming the helix, as shown in Fig **648**. Three lengths of wire are wound into the box for the spiral centre and one length is continued on to the spiral of the tube. The two unused lengths of the spiral are cut off at the mouth of the box.

Spherical

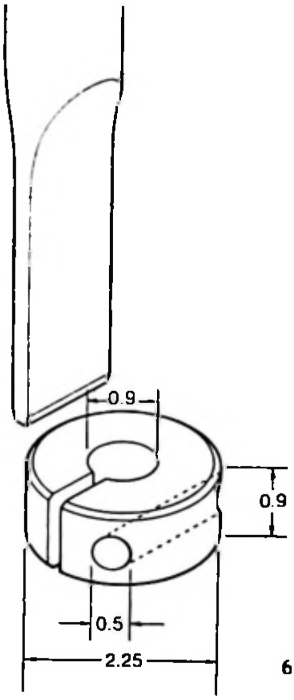
The spherical spring was sometimes used by Swiss chronometer makers. It is formed in the same way as the helical spring by winding on to a former. The former is composed of a number of discs held together with a centre screw. The surface is cut with a groove to take the wire which is held at each end by a screw head. After hardening and tempering the clamping screws are removed, the centre screw withdrawn and the pieces of the sphere removed through the coils of the spring, as shown in Fig **649**. Such springs offer no practical advantage to the watchmaker but are much admired by some watch collectors, who love craftsmanship the more if it offers a suggestion of extra difficulty of accomplishment.



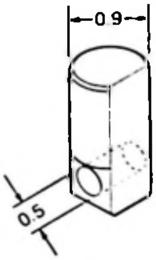
649 Former for spherical spring

Spring Studs and Collets

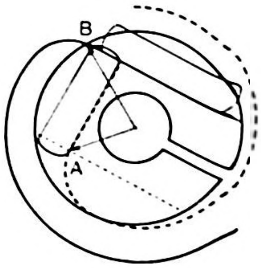
The simplest forms of stud and collet are shown in Figs **650a** and **b**. The stud has a flat or sometimes a groove to ensure positive orientation of the pinning hole. The collet has a slot to allow a certain amount of latitude in the diameter of the arbor to which it is to be fitted. The slot is also useful for removing the collet from its arbor, using a flat-bladed tool in the slot. Fit the tool into the slot and twist while pulling up and off. This form of collet is entirely satisfactory and suitable for any type of watch. With it the radius of the pinning point of the spring equals the radius of the collet. As seen at *A* in Fig **651** by flattening the sides of the collet and turning the pinning point through 90° its radius is reduced for the same diameter collet as seen at *B*. Changing the radius of the pinning point can be useful to the adjustment for isochronism.



650a Balance-spring collet



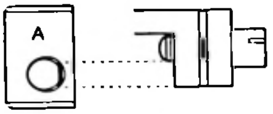
650b Balance-spring stud



651 Reduced pinning radius of flattened collet

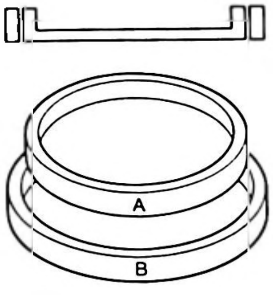
The Stud

The stud shown in Fig **650b** is simply made from a steel rod. File the flat to locate the stud in the watch and ensure exact orientation of the pinning hole.



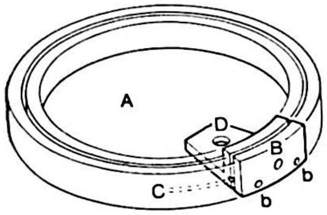
652 Height advantage of clamp stud

It can be seen in Fig **652** that the stud *A* of the pinned spring extends downwards below the width of the spring. With a clamping stud the spring is flush with the underside of the stud. This is useful in a watch with an overcoil spring and will allow greater freedom to the spiral below the stud. The clamp may be spaced above the spring with screws or a piece of the balance spring. Where the watch has no regulator, but a means of adjustment for isochronism is required, the clamp can be extended to form a bracket for an adjusting screw. Examples of studs can be seen in the watches illustrated in Plates II and IV.



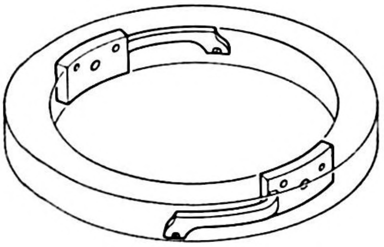
653 Blanks for stud

To make the stud, turn a dish of carbon steel to the form shown at *A* in Fig **653** and the collar *B* surrounding it. The outside radius of *A* is the terminal radius of the spring. The inside diameter of *B* is equal to the outside diameter of *A* plus the thickness of the spring. Fit *A* into *B* and drill through 0.3 mm at mid-height, as in Fig **654**. Tap the hole in *A* 0.4 mm diameter and open the hole in *B* to accept the 0.4 mm screw. Secure *B* to *A* with the screw and drill through *B* 0.3 mm to touch *A* close to the top at positions *bb*. The drill will mark *A* after passing through at *bb* and, at the height of the marks, turn a groove in *A*, as seen at *c*. This groove will locate the points of the steady screws at *bb* to prevent a misalignment of the clamp. Drill the hole *D*, 0.6 mm for the stud fixing screw and cut the stud from the dish. Thread the steady screw holes 0.4 mm diameter and cut the clamp from the collar.



654 Drillings for the plate

When the isochronal adjusting screw is required the collar should be made thicker and filed away, as shown in Fig **655**. Note that two clamps can be cut from the collar and these are shown to make clearer the inside and outside views of the clamp.

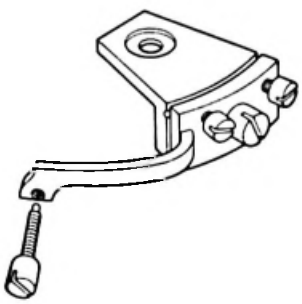


655 Stud with adjusting screw bracket

Thread the hole for the isochronal screw 0.4 mm diameter. Form the thread with a tapered tap until the screw will just enter the thread stiffly. File the underside to break through the edge of the hole. Do not fit the screw until the clamp is hardened and tempered.

Recess the stud screw hole and finish the pieces overall with a smooth-grained finish from an Arkansas slip. Harden and temper to a medium blue and finally finish the surfaces as required.

Make the isochronal screw with a deep parallel slot to take a flat-bladed tool, and drill holes through at 90° for a pin-ended tool. The final adjustment of the screw is delicate and pressure from the screwdriver must be avoided. The final form of the clamp is shown in Fig **656**.



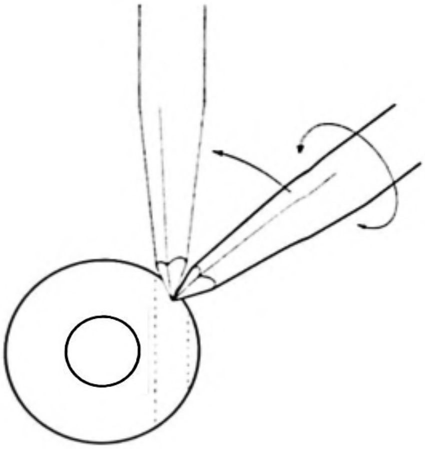
656 Completed stud with adjusting screw

The Circular Collet

Turn the collet in the lathe from brass rod. Leave the diameter oversized for final finishing after drilling. Make a centre with the point of the graver and drill the centre hole. Part the collet from the rod and thread on to a broach for convenience in holding.

With a sharp-pointed chamfer make a deep sink to locate the drill for the pinning hole. Start the chamfer radially and, as the sink deepens, bring it round to the required chord of the circumference, as shown in Fig 657. The dashed lines indicate the path that the drill will take. Drill the hole and with the collet on an arbor in the lathe clean off the marks from the chamfering tool. Finally cut the slot using the arrangement shown in Fig 302. The dimensions of the collet shown in Fig 650a are suitable for the *tourbillon* illustrated in Plate IV.

The flat-sided collet is turned and drilled in the same way but is brought to final diameter before parting off. File the sides flat before drilling the pinning hole.


657 Starting a chamfer for a chordal drilling

To Fit the Balance Spring

Vibrating to Length

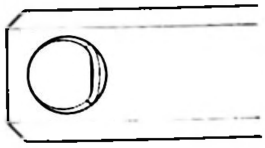
If the spring is a flat spiral it should be vibrated on the balance to a length that will offer the required short arc gain to overcome escapement error.

Lay the spring over the collet to observe the minimum length of spring that will need to be cut from the centre to free the edge of the collet. Straighten the end of the spring to enter the collet pin hole and secure with a temporary pin. The pin needs to be only a light press-fit in the hole, just sufficient to hold the spring during the initial vibrations.

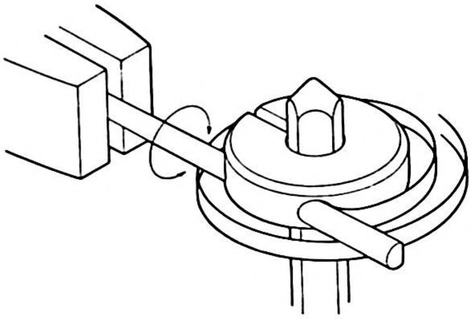
Hold the spring in the tweezers to suspend the balance above the glass of a watch. Set the balance vibrating through about 90° and count alternate vibrations for half a minute. Alter the length of the spring as required by shifting in the tweezers. When the required number of vibrations is within a half-second, extend the counting to one-minute intervals. At the same time an assessment must be made of the suitability of the spring. If it is to be pinned in to suit the escapement error, it may be necessary to alter the length at the inner end. If, for example, when vibrating to a correct count, the spring is a quarter turn short of whole turns it can be corrected by lengthening at the outer end and cutting out a full turn from the centre. Any further small correction can be made by adjusting the weight of the balance.

If the spring is to have an overcoil cut the outer coil a quarter turn short of the required number of turns.

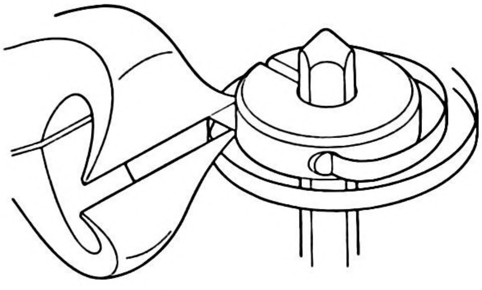
Pinning to the Collet


658 Correct form of collet pin

When the length is satisfactory the pinning at the collet can be made permanent. File the pin to a long taper and burnish the surface. File a flat to allow room for the spring. Fit the collet firmly to a broach and try the pin in the collet hole with a piece of the surplus spring. Grip the small end in pliers and pull the wire tight into the hole. The pin will cause the spring to bow and when this happens it is tight enough and of the correct shape to hold the spring firmly, as in Fig 658. Make a mark on the pin at the entrance to the hole to indicate its position when fully home. Withdraw from the hole and examine the piece of spring to be sure it was gripped throughout the length of the hole. Fit the balance spring and refit the pin as before. Before pulling tight into the hole rotate as required to bring the inner coil of the spring parallel with the collet faces, as in Fig 659. Finally pull fully home up to the mark which will indicate when the spring is tightly held. Cut off the ends with sharp side-cutters. These should be especially prepared to reach into the entrance of the hole to leave the ends of the pin flat, as shown in Fig 660.



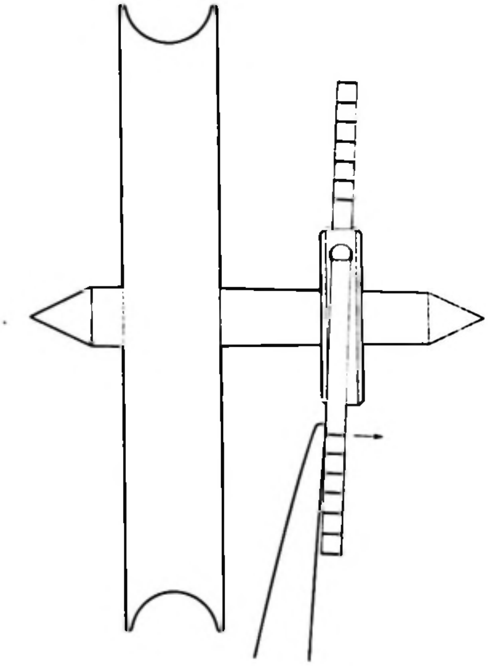
659 Setting the spring level



660 Cutting the pin to length

Centring and Truing

Make the initial corrections for concentricity and flatness of the spring with the collet held on a smooth broach. Rotate the broach slowly between the fingers while examining the centre coils of the spring. If any adjustment is required to make the spring flat this will be minimal. Make the alteration by raising or lowering the half coil opposite the pinning point. Push up or down with a point, as in Fig 661.



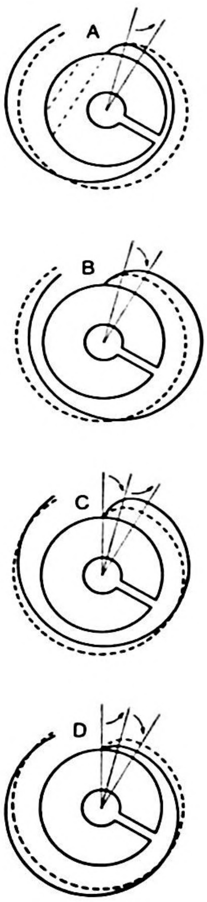
661 Setting the spring level

Corrections for concentricity must be made in the first quarter turn of the inner coil. Fig **662**, *A* to *D*, shows the type of correction required for the principal errors of orientation of the curve to the pinning point. At *A* and *B* the radius of the termination is correct but the angle of the curve into the collet is incorrect. This can be corrected in a single alteration in the direction of the arrow.

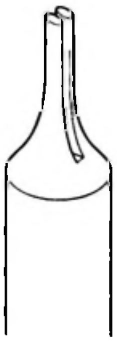
At *C* and *D* the radius is incorrect but this cannot be altered without unpinning. The simpler method is to alter the curve in two parts. The first alteration, at the pinning point, will correct the radius. The second will alter the curve as at *A* or *B* to re-centre the coil. The direction of bending is shown by the arrows. Fig **663** shows the tool used for bending. This is made by reducing the end of a steel rod and slitting with a circular saw in the lathe to ensure truly vertical prongs.

With a piece of peg-wood, hold the collet down to a flat surface and straddle the coil with the prongs. Hold the tool upright with the ends of the prongs resting on the flat surface, as in Fig **664**, and rotate in the fingers as necessary. This method will prevent the coil rising or falling out of parallel with the collet faces, as in Fig **664**.

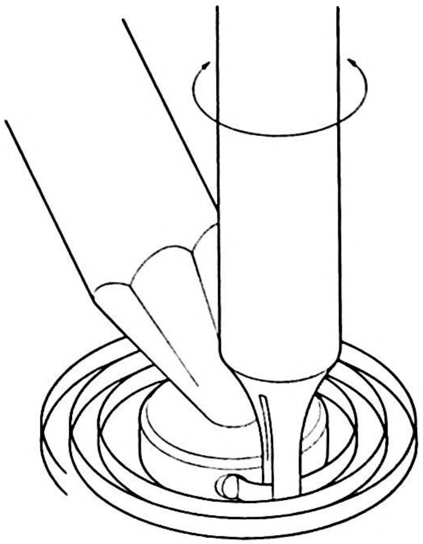
Make the final observation with the collet fitted to the balance wheel as it revolves freely in the callipers. Allow the balance to make several slow revolutions while closely observing the centre coils of the spring. These should run smoothly to or from the centre of the collet without hesitation or jerking. A small fault will not be visible when the spring is stationary. By spinning the balance the fault can be located rhythmically, relative to some part of the balance and the correction applied with the balance stationary. Note that the prongs can rest on the surface of the balance centre so that it is not necessary to remove the spring from the balance to make corrections.



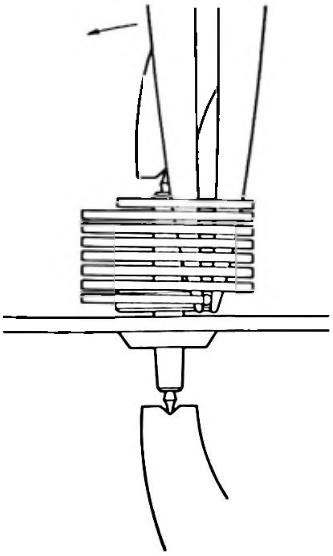
662 Setting the spring true with the collet



663 Tool for bending the spring



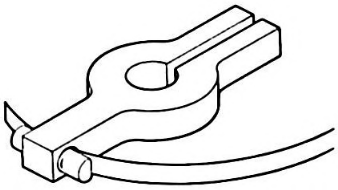
664 Setting the inner curve



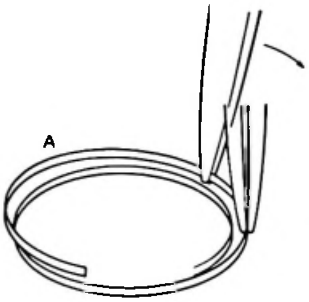
665 Setting the helical spring

Helical Springs

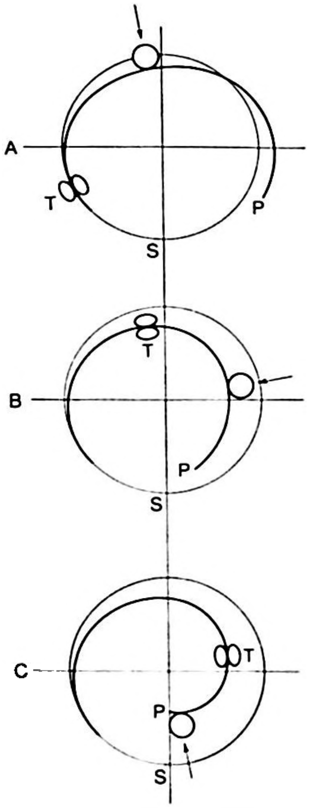
Pins for helical spring collets are prepared in the same way as for the spiral spring collets. Prepare the wire as before and make a trial fitting to the collet with a piece of surplus spring. Mark the wire at the large end close to the hole. Withdraw and cut off the pin at the mark. Lightly fit the spring to the collet with the cut pin. Bring the spring vertical to the balance by rotating the pin with tweezers, as in Fig 665. Press the pin fully home with the pliers so that the mark is at the face of the collet hole. Finally cut off the surplus wire with sharp end-cutters to leave the ends symmetrical, as in Fig 666.



666 Pin for helical spring



667 Raising the overcoil



668 Setting the terminal curve

Terminal Curves

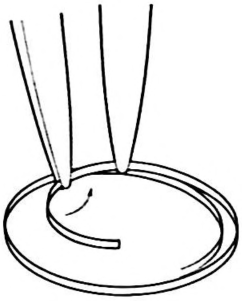
To form the Breguet overcoil to the flat spring, grip the outer coil in tweezers at a distance of three-quarters of a turn from the pinning point. With a second pair of tweezers grip the spring towards the free end at a distance of one-eighth of a turn from the first pair. Hold the first upright and in contact with a flat surface. Lean the second pair to twist the spring and raise the outer coil so that the highest point of the coil, *A*, in Fig 667, is at the final required height of the overcoil. The coil can now be bent to shape. This is most easily done by holding in brass tweezers and bending with sharpened peg-wood. The bending is done basically in three parts and finished by secondary, intermediate bends.

The order of bending is shown in Fig 668 at *A*, *B* and *C*. In each diagram *S* is the start of the rise of the coil and *P* is the final pinning point. Make the first bend by gripping with tweezers at *T*, seen in *A*, and pressing inwards with the wood stick to produce a uniform smaller radius to the first half of the curve. Move the tweezers to the position *T*, seen in *B*, and make the second bend. Again move the tweezers and make the third bend, as seen in *C*. Finish the curve to the required shape by moving the tweezers along the length to any position required to make the secondary bends. The spring will now be as shown in Fig 669 and the curve can be raised parallel with the spiral using two pairs of tweezers in the manner shown in Fig 667. Start the manipulation at half the length of the curve to raise only the last third up to the pinning point. The final curve will then begin to rise immediately beneath the pinning point for a quarter of the last turn of the main spiral before turning into the terminal curve.

Formed in this way the spring material will suffer the least deformity, and stresses caused by the change of elevation will be kept to a minimum. It is usually suggested that the curve is formed with shaped tweezers. These are useful if a sufficient range of sizes is available. The method described is quicker and offers greater flexibility of overcoil form.

The form of the curve need follow no precise formula or pattern. Provided the length is about three-fifths of the length of the final turn of the spiral and the radius gradually diminishes by about one-third of the radius of the spiral it will be satisfactory. The final shape will depend upon the isochronal requirements of the escapement.

Curves for helical springs can be formed in exactly the same way except that they need no raising.


669 Setting the curve level

12

CASEMAKING

Soldering

Gold and silver are the principal solders required by the watchmaker. The melting point of the solder will depend on the nature of the alloy. A skilled goldsmith can mix his own alloys. The inexperienced would do better to purchase his materials from a specialist manufacturer who can determine the melting point with certainty.

The Blow Torch

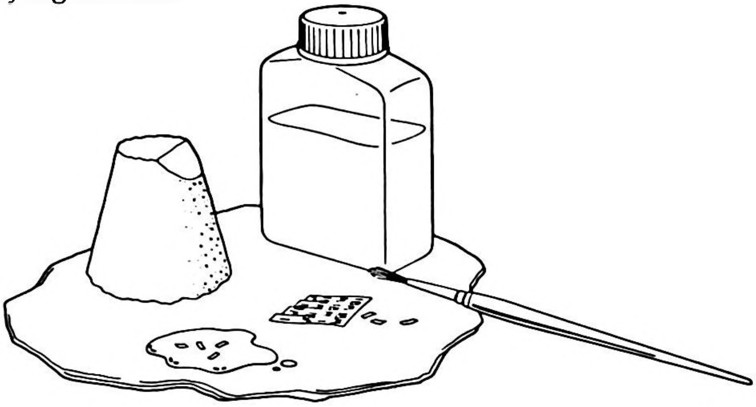
The most flexible means of applying the necessary heat is with a blow torch. At one time coal gas and air, compressed by foot bellows, was the most convenient form. Modern torches use propane or butane gas in containers under pressure. The required amount of air is drawn into the burner automatically and so only one pipe is required. The intensity of heat can be varied by altering the gas flow, while the size of the flame is varied by changing the nozzle. Container gases produce a hotter flame than coal gas and must be used with caution to avoid burning the solder by direct application of the flame.

Solder

When purchased the solder is in the form of flat sheets stamped overall with the melting grade. There are three principal grades, hard, medium and easy, and they can usually be obtained in various colours to suit the colour of the gold being fashioned. Slit the edge of the sheet with the snips, as shown in Fig 670, and detach pieces of a convenient size. Note the grade and colour in this instance is medium eighteen carat, indicated by the marks 18M.

Flux

The traditional flux for gold and silver soldering is borax. Other fluxes, with greater ability to absorb oxidation and surface impurities, are now available in powder form. But borax is more suited to the needs of the watchmaker who must often tie the joint with iron wire to locate the component for soldering. The borax is reluctant to absorb iron oxide and so the wire will not become soldered to the work as would be the case with a more efficient flux. It is essential that the surface to be soldered is quite clean and bright before applying the flux.



670 Clip pieces of solder into the borax paste

Preparing the Flux and Solder

Borax can be purchased in the form of a cone which is conveniently rubbed to a paste with water on a piece of slate. Apply the water to the slate using a small pill bottle with a pierced cap. Place the cap in contact with the slate and a sufficient amount of water will be drawn out by capillarity. Rub the borax into a thin, wet continuous paste. If too stiff, the paste will dry out before it can be conveniently applied to the work. If too wet, it will not form a continuous film on the work.

When clipping off the pieces of solder to be used, allow them to fall into the paste. This will keep them conveniently located and at the same time ensure they are well covered with flux ready for use. Apply the paste thinly to the area to be soldered using a fine paint brush. Before the flux dries place the solder in position. Apply the blow torch gently to dry out the flux completely before raising the work to soldering temperature. To avoid the flux bubbling and displacing the solder, play the flame on the surrounding areas and allow the heat to build up slowly at the joint.

Positioning the Solder

Place the solder in position so that it is in contact with both halves of the joint but at the same time shielded from the direct heat of the flame. This is especially necessary when using low melting-point solder, which will quickly melt in direct flame and may not run into the joint. If the solder melts without running into the joint it will burn a crater into the surface of the component and leave a permanent scar.

The application of the flux can assist the jointing by acting as a capillary for the solder. It is important that the flux is of the correct density of paste and applied only in the areas where the solder is required to run. It is also important to use exactly the right amount of solder. A surprisingly small amount is necessary if the flux is properly applied to a well-made joint. A badly fitted joint cannot be made good by filling with solder. Only very rarely can an excess of solder be removed to effect an improvement in the final appearance. The correct amount will leave the joint quite clean and with a tiny fillet of solder deep in the corners. Experience is the final guide and this can be had by practice with pieces of scrap metal.

The solder cannot flow deep into the corners if the heat is not evenly distributed. With a small object, such as a watch case, the whole of the component should be raised to red heat. The actual soldering temperature is needed only at the joint which must be heated until the solder runs. The surrounding area need only be hot enough to avoid drawing the heat away from the joint.

Grade of Solder

Sometimes several joints are needed in one component and, to avoid disturbing early joints, lower melting-point solders are required as the work proceeds. It is not always possible to avoid two or more joints falling in the same place. When this happens great care is needed in avoiding excessive heat that may disturb the earlier jointing.

Cleaning the Joint

After each application of heat the work should be allowed to cool until, when shaded from direct light, no trace of red heat is visible. This condition is known as 'black heat' and is the maximum safe heat (approximately 450 °C) at which the metal can be quenched without becoming annealed. The flux should fall away during the quenching or easily brush off with warm water. If it does not it can be removed by immersing the work in a hot solution of 10 per cent to 15 per cent sulphuric acid in water. The acid must be added slowly to cold water and the working temperature raised to just below boiling. Use brass or wood forceps with the solution and remove the work immediately all discoloration from the flux and oxidation has gone. Finally rinse in clean water.

Materials for Cases

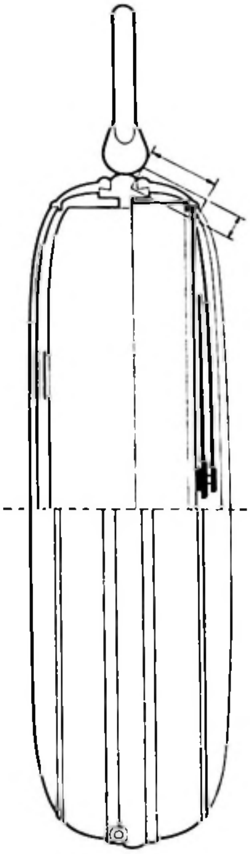
The cases of good-quality watches are usually made of gold or silver or a mixture of the two metals. Gold is usually preferred, probably because of the warmth of its colour. Silver tarnishes and will turn almost black if neglected. Platinum or white gold are sometimes used when a non-tarnishing silver-coloured metal is required. Advice on the grades, colours and types of metal available can be obtained from the supplier. For watch cases, eighteen-carat gold or standard silver are usual.

Both silver and gold can be bought in various qualities. In their purest form both are too soft to withstand general daily use. Both materials require fluxing before soldering. Platinum does not oxidize in heat and so requires no flux. The metal can be purchased in various degrees of hardness or in the annealed condition.

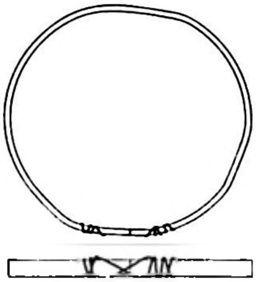
The bezels and bands of watchcases can be made from annealed material. This will ease the work of forming the circles ready for soldering and in bringing them to size and shape. The cold-working entailed in sizing will re-harden the components to ensure rigidity. Excessively cold-worked material must be annealed to prevent cracking and splitting. The amount of cold-working and the annealing temperatures depend on the type of alloy in use. The supplier can give all directions to ensure the best final condition of the alloy.

As a general rule gold and silver should not be heated above 650 °C for annealing. In a shaded corner of the workshop this will produce a dull-red colour. At this temperature the grains of the metal, deformed by work-hardening, will relax and the metal will become soft. Silver and some gold alloys can be held in this condition by quenching in water as soon as the visible red heat has gone.

Some gold alloys should be left to cool slowly in air, while others must be quenched from red heat. And some red alloys become harder by precipitation of copper if allowed to cool slowly. The inexperienced should follow closely the supplier's advice for working the material.



671 Assessing the dimensions of the raw material



672 Forming the ring

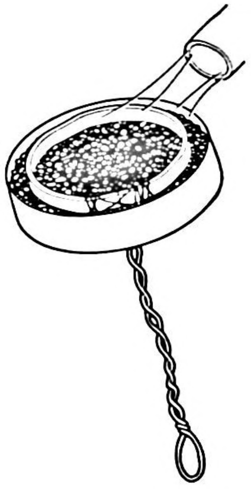
Forming the Bands

The method of casemaking to be described would not be economical for quantity production. It is the traditional method used for making individually styled cases. The materials are purchased in strip form for the bands and the bezels, and rolled sheet for the covers. The dimensions will depend on the diameter of the movement and the style of the case. For a case such as that illustrated in Plate II make a sketch in side elevation of the movement and draw in the case components. In Fig 671 the dimensions of the material required are shown by arrowed lines containing the cross-section of the component. The required length of the strip is equal to the diameter of the movement multiplied by three and one-third, that is $L = D \times 3.3$.

File the ends of the strip square and bend into a ring. It will help to make the faces meet exactly if the ends are first curved around the horn of an anvil or similar convenient curve. The completed ring is shown in Fig 672. It does not need to be round. Check carefully to see that no sideways stress is being constrained by the friction of contact of the faces. The faces do not need to be hard pressed together but should be in contact to reduce the width of the joint when soldered. To prevent the faces parting under the heat tie the ends together with stiff iron wire as shown.

Soldering the Joint

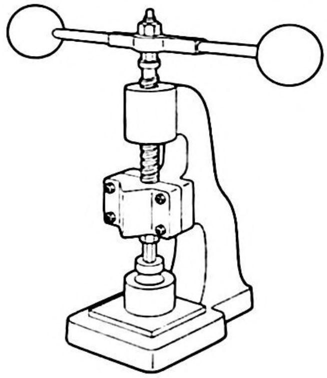
For this first joint use the hardest solder. Place the band on the iron-wire pad as shown in Fig 673. The pad is supported on a handle so that the work can be rotated in the hand to distribute the heat without moving the torch. The container for the pad is not essential but provides a useful guard against the work sliding off while attention is concentrated on the area under the flame. Note that a large flame is used to distribute the heat, which must rise to a maximum at the joint. Quench at black-heat and remove the iron wire. File off the surplus solder to leave a smooth surface at the joint.



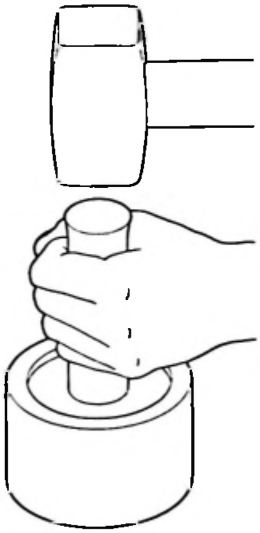
673 Soldering the joint

Reducing to Size

The ring must now be made truly circular and to size. This is done by forcing the ring into a tapered tube by means of a series of sized discs; Fig **674** shows the tool set up for use in a small press. This is by far the most convenient way to reduce the rings. If a press is not available the discs can be forced with a hammer, as was the original method, shown in Fig **675**.

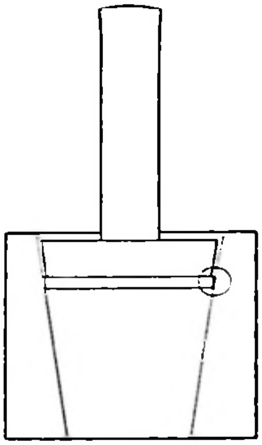


674 Tool for pressing rings

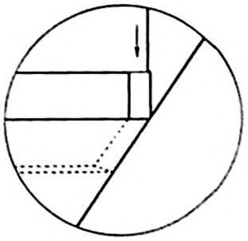


675 Forming rings by hand

The ring in position ready for reducing is shown in Fig **676**. It can be reduced by only a small amount before the disc will jam in the taper. A series of sized discs are required and, with tapered edges, two advances can be made for each disc. By this means the ring can be made quite round and brought exactly to size. The ring will become tapered as it is forced into the tube. For the middle band of a case this taper can be removed by turning as the ring is brought to shape. The taper is generally useful for the bezels and can be varied by changing the tube for one of an appropriate taper to suit the required shape of the work. A shallow bezel requires a fast taper, as shown in Fig **676a**. The dashed line shows the shape that the bezel will become after the forcing. Note that the bezel becomes deeper and thicker at the line of greatest pressure. The compression increases the hardness of the metal and introduces stresses. The increased hardness is not harmful but like the stresses will be removed by subsequent soldering operations. If there are none the stress can be relieved by heating the component to about 450 °C and quenching in water.

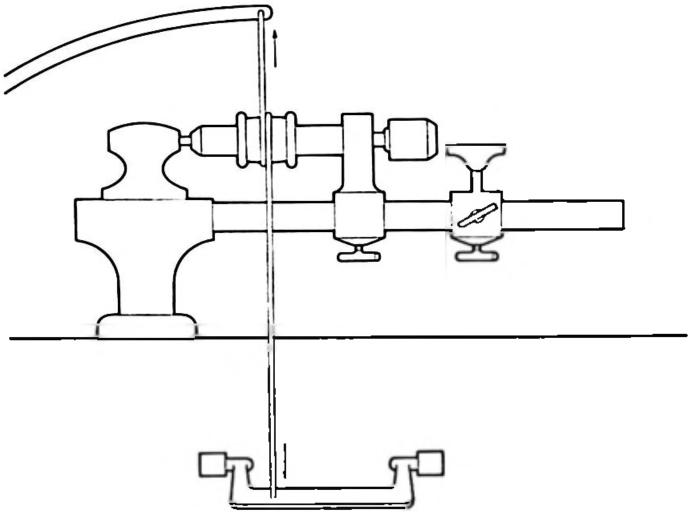


676 Action of tapered former



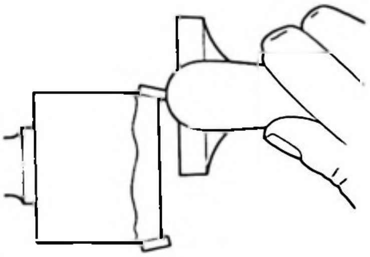
676a Detail of forming

Turning the Ring
After making to size the rings must be turned to fit the movement. The traditional method of turning used by casemakers is by pole lathe. This is a simple spindle with threaded nose turned by a cord attached to a spring pole above and a foot treadle below. This leaves both hands free to attend to the work. A hand bow was very rarely used as it left only one hand free.



677 Casemaker's pole lathe

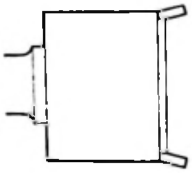
The pole lathe is shown in Fig 677. The work is fitted to a boxwood chuck turned to size. The work may be gripped by the inner or outer edges. Prepare a true edge by pressing the ring on to a taper. Bring it true with the handle of the graver rested on the 'T' rest, as in Fig 678, as the work is revolved.



678 Truing the ring

Turn the inside edge and the face with a sharp graver lubricated with cutting oil. Turpentine was traditionally used to lubricate but modern cutting oils stay wet longer. A dry cutting edge will leave a rough surface to the work. Retrim the chuck and fit the work by the true edge as shown in Fig 679.

The turning can be done more quickly in the motor-driven lathe because it has a continuous direction of rotation. But care is needed to prevent the work overheating and, by expansion, detaching from the chuck. Keep the headstock spindle speed down to about 300 rpm. A damp sponge or piece of leather held against the work will hold the temperature down. This is especially useful for slightly expanding the edge of the wood chuck to tighten the grip of the work.

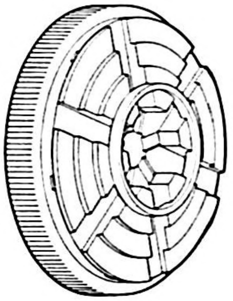


679 Fitting at the turned edge

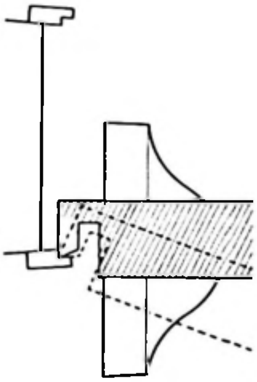
A slide rest can be used for all the operations of turning a case. A narrower cutting edge will be necessary to prevent tool chatter. After all cuts smooth the surface with water-of-Ayr stone cut into convenient shapes to reach into corners. Finish with wet pumice powder on a piece of cork.

The wood chuck may be gripped in a centre lathe when the sequence of the operations will be the same as for the pole lathe. Alternatively, the six-jawed step chuck can be used as shown in Fig **680**. The jaws must be turned to the required size for the work. Note the ring gripped by the inner step to ensure the expanding jaws are pulled equally against the scroll thread to ensure a concentric cut when turning to size. When turning the contracting jaws grip the ring inside the innermost step. In both cases turn the jaws to fit the component then remove the ring and contract or expand the jaws as required to grip. Mark the ring to correspond with the newly turned step. Its exact diameter can easily be rediscovered by replacing the ring to the innermost step.

Start with the middle band and fit the movement. Grip the graver firmly downwards on to the 'T' rest to prevent the cutting edge following the work. Use only the tip of the cutting edge until the high spots are removed and a full cut can be taken to make the work truly circular. Fig **681** shows a suitable inside cutting tool made from a file. Formed in this way the cutter cannot tip if it catches in the work surface and can be conveniently swivelled to bring the tip into contact.



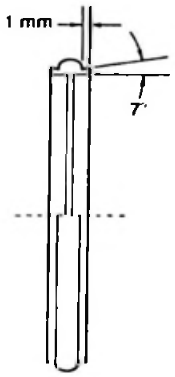
680 Six-jawed chuck



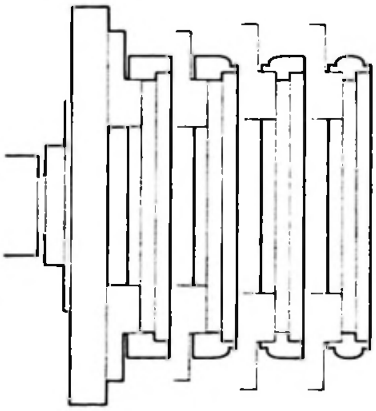
681 Cutter made from an old file

The Snap Rings

When the movement recess is completed turn the snap ring for the front bezel. Reverse the work on the chuck, clear away the surplus metal and turn the snap ring for the back bezel. The dimensions of the snap rings and the draw angles vary with the size and form of the case. A thin bezel can have a greater draw angle than a thicker, less flexible bezel. If the bezel needs to be opened for hand setting or winding it will need a curved draw to make the action smoother. Fortunately this can be attended to when the case is finished and just prior to final pinning. Fig **682** gives an indication of the requirements in the early stages of a pocket-watch case. Fig **683** shows the four stages of turning the band.

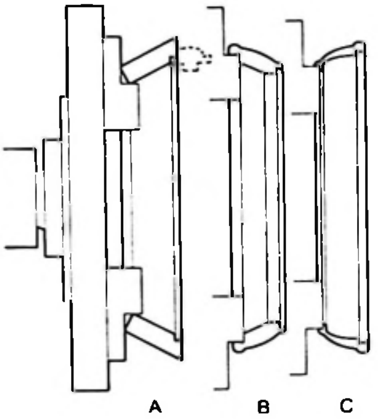


682 Detail of the snap ring



683 Four stages of turning the middle ring

Turn the front bezel to fit tightly on to the snap ring making the step in the bezel deeper than the height of the snap ring, as in Fig 684 at *A*. Reverse the bezel and open the inside to the diameter of the dial, as at *B*. Turn the groove for the crystal and form the shape of the outer surface. Finally reverse the bezel and clear away the unwanted thickness from the inside, as at C. The back bezel is made in the same way and to the same dimensions.



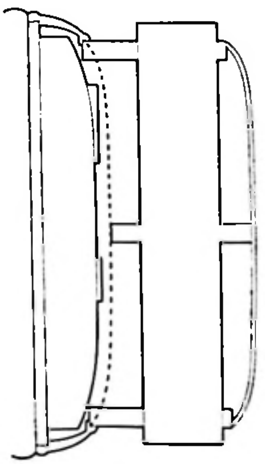
684 Three stages in forming a bezel

The Back Cover

Cut a disc of metal for the back 0.7 mm thick and a little larger in diameter than the groove in the back bezel. The back will be snapped into this groove and need no further fixing.

It is important to remove all rolling stresses from the disc before shaping the dome. Resistance to bending will be greater along the rolled axis and the dome will not rise truly. If it is required to engine-turn the case the back should be true to avoid unnecessary depth of cut.

After heat treatment clean both sides with soft water-of-Ayr stone under running water. This will leave a fine-grain finish which will be beneficial when mounting the back with cement for turning the edge.

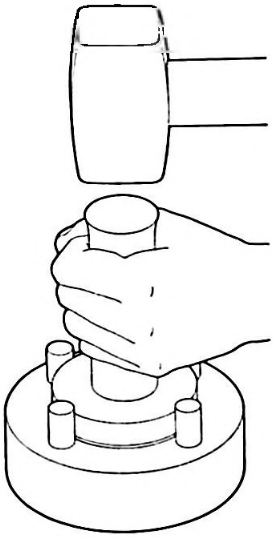


685 Gauging the height of the back

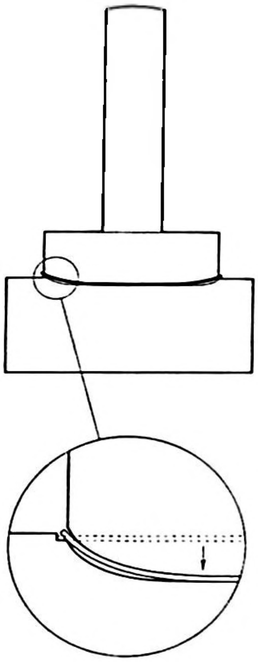
Forming the Back

Measure the required depth of curvature with the gauge shown in Fig 685. If no inner back is required for the case the depth can be measured from the movement.

The back is formed in a simple tool preferably used in a press. For an individual back the tool can be made from brass or boxwood. For greater durability steel is preferable. If a press tool is not available the two halves of the tool can be located with pins and hammered together to form the dome, as in Fig 686. Note that in Fig 687 it is not necessary for both halves of the tool to have the same curvature. The metal will curve according to the line of least resistance but sharp curves will be avoided if the curves of the upper half of the tool have a greater radius than those of the lower half. The final curve should increase gradually and smoothly towards the edge.

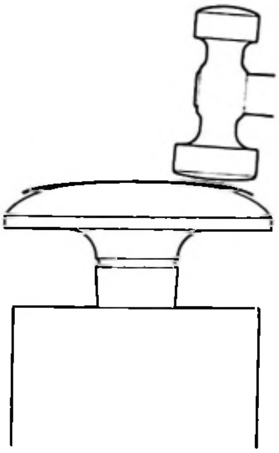


686 Forming the back by hand

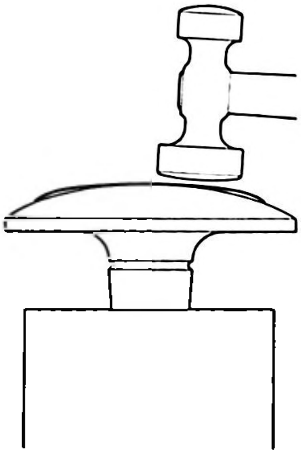


687 Form of the press-tool curve

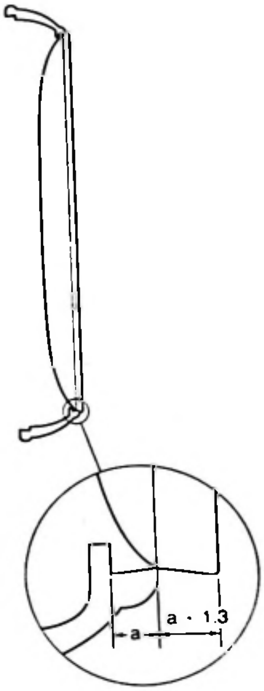
If the depth of curvature is insufficient the tool may be altered and the back re-pressed. Alternatively it can be deepened on a mushroom-shaped anvil with a curved and polished hammer, as in Fig 688. This will stretch the metal at the hammer line to deepen the curve towards the edge. A curve that is too deep can be reduced on a flatter anvil, as in Fig 689, but the curve must be close to avoid a circular furrow at the peak of the curve.



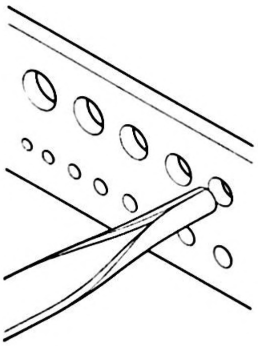
688 Increasing the curvature



689 Decreasing the curvature



690 Fitting the back to the bezel groove



691 Starting the tube in the draw plate

Turning the Back

When the height of curve is correct, as indicated by the depth gauge, the back can be turned to diameter. Cement it to a wood chuck in the lathe. If the face of the wood is true the work will be flat and it will be necessary only to make true in the round. This can be done with an independent four-jaw chuck. The chuck shown in Fig **717** is especially designed for rapidly truing discs and is easily made.

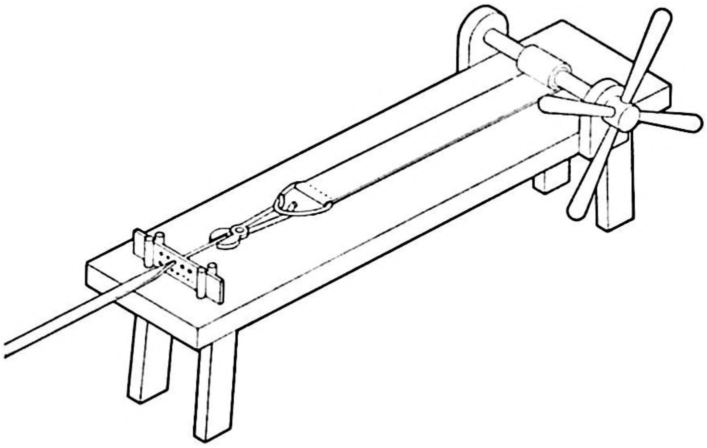
Turn the edge to a 10° taper to match the groove in the bezel. Offer up the bezel with the back in the lathe. The ideal fit to the groove is shown in Fig **690** where the smallest diameter of the edge of the back equals the smallest diameter of the edge of the groove. Note that the edge of the back, by reason of the curvature, is now deeper than the thickness of the metal. This will ensure a tight fit that cannot rotate in the groove. Note also the small radius at the extreme edge to assist entry into the groove when finally snapping into the bezel.

The Hinge

The hinge is made from drawn tube. Traditionally this was made by the casemaker from sheet material formed into a tube for a sufficient length to enter a draw plate. Fig **691** shows the form of the material ready for drawing. It is drawn through a series of holes of ever-decreasing diameter until the required size of tube is reached. A draw bench is needed for this work.

Fig **692** shows a typical draw bench which is still readily available from jewellers' tool suppliers. The draw plate is held in a bracket at one end. At the other end a capstan wheel is turned to draw the material with a clamp and chain or a leather strap.

The tubing can be purchased from the bullion house but the standard sizes of tube are usually too thin in the wall and not strong enough. It can usually be supplied to special order if the dimensions are given. A suitable size for the case in hand would be 1.4 mm diameter with a 0.7 mm bore.

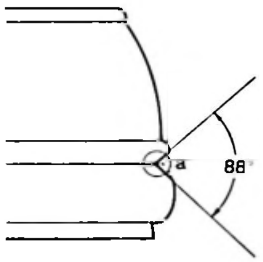


692 Draw bench

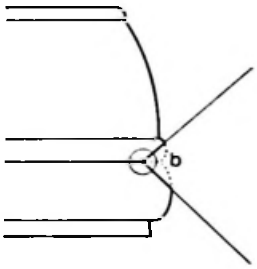
Position of the Hinge

The tube must be fitted into a space formed by a groove in the band and an aligned groove in the bezel. The position of the grooves is important if the hinge is to be both strong and neat. If it is too close to the edge the joint will be weak and the bezel will open too far and look untidy. If too far in from the edge the bezel will not fully open without removing an excessive amount of metal from its edge and the edge of the band.

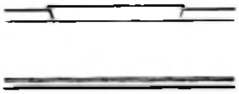
The effect of this is shown in Fig **693a** where the hinge is well placed and the banking at *a* is small and does not weaken the joint. In Fig **693b** the hinge is too far in and the banking at *b* is too large and has weakened the joint in the bezel.



693a Correct position for the hinge



693b Hinge too far in



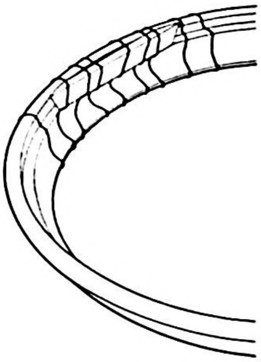
694 Elevation of bearer

The Bearer

Before the groove in the bezel can be formed a bearer must be fitted to support the tube. This is shown in Fig **694** soldered to the snap groove of the bezel. File the ends at an angle to fit the curve of the snap groove. Fig **695** shows the back of the bearer filed at the ends to tip the bottom edge into the groove. Bind the bearer into position with iron wire pressed into the corners to hold it at the correct angle. Fix with hard-grade solder placed in the ends close to the points of contact. It is not necessary to fill the gap with solder. Medium solder could be used if the soldering is close to an earlier joint. In this instance it is not, and hard solder will enable the later use of medium for fixing the tube.

If the position of the first joint has been lost it can be found by oxidizing the ring by heating when the solder will show a different colour.

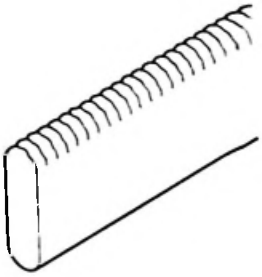
When the soldering is completed file the bearer flush with the surface of the edge and it is ready to receive the groove for the tube.



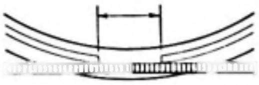
695 Bearer wired into position

Clearing the Groove

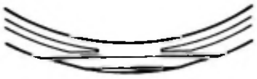
The grooves are cut with a curved edged, coarse file, as shown in Fig **696**. Make a guide for the file by cutting through the snap ring of the band as in Fig **697**. File the groove to a depth of little less than half the diameter of the tube. File the ends of the snap ring to the form shown in Fig **698** to give freedom to the bearer and to enable the bezel to be snapped on. With a needle file mark the position for the bezel groove and cut this to the same depth as the groove in the



696 Groove-cutting file



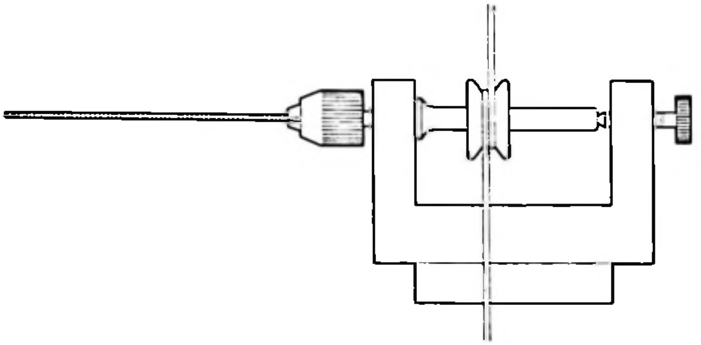
697 Forming the guide for the grooving file



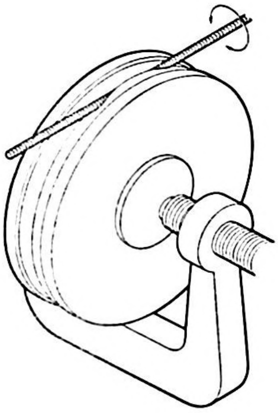
698 Shape of the snap ring at the bearer position

band. Check the position of the bezel groove as the cutting proceeds to ensure alignment with the groove in the band.

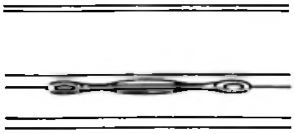
Some practice is required to form the grooves uniformly throughout their length. Place the ring flat on the bench with a piece of soft leather beneath to prevent it sliding about. Hold the file firmly and watch that it is kept upright and level with the bench surface throughout the length of the stroke. The two grooves must now be brought to a single round passage to take the tube. This is done with a coarse, round file especially made for the purpose. It can be used by hand in a pin vice or, preferably, with a spindle worked by a bow, as in Fig 699. The file is used as a broach or reamer to open the hole and make it parallel. The hole should be opened until the tube can be passed freely through without binding. Keep the bezel firmly up to the band with two discs and a clamp, as in Fig 700. The hole can be enlarged only by the use of a file of larger diameter. If one is not readily available it is simply made from carbon-steel wire coarsely chiselled to raise the cutting burrs.



699 Broaching spindle



700 Broaching the hole parallel



701 Banking clearance

The edge must now be filed to give the banking clearance, as shown in Fig 693a. Pivot the two halves of the case on the tube to check the progress. File the parts to allow an opening of just less than 90°. A greater angle looks untidy and is a sign of poor construction. When completed, the banking clearance will look as in Fig 701.

Soldering the Hinge

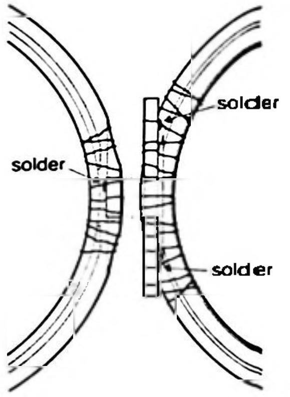
Cut the tubing to length and wire into position, as in Fig 702. Place a small piece of medium solder close into the joint under the wire as indicated by the arrows. Ensure that the ends of the tube are quite square and smooth. If there is a seam in the tube place this in contact with the joint where it cannot show. Carefully hold the two halves together to be sure that the tube is correctly positioned, indicated by the dashed lines, and finally apply the heat to fuse the solder. If the bearer is put in with medium solder the tube can be soldered with an easy-grade solder. However, this is not essential and medium-grade solder may be used for both operations. The bearer cannot move once the tube is wired in position and joints are reluctant to part once the solder has fused. Easy solder should be avoided if possible for it may melt before the work is sufficiently hot to receive it and, in eventually running to the joint, leave behind a scar that cannot be erased.

The correct amount of solder is vitally important to avoid a surplus in the groove at the ends of the tube. Even with the correct amount of solder a small fillet will form at this point. It can be removed with a graver, shown in Fig 703.

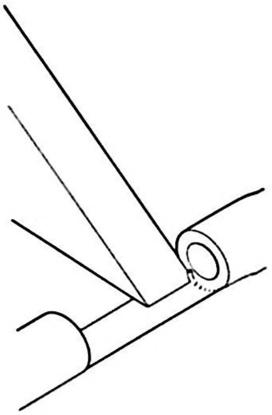
Because the tube was a free fit in the hole the two parts will be slightly misaligned after soldering as the clearance was taken up on opposite sides. This will be useful in the final pinning because the resultant bow in the pin will pull the two halves together. To preserve this condition broach the two halves separately to take the taper of the pin.

Thumb Piece

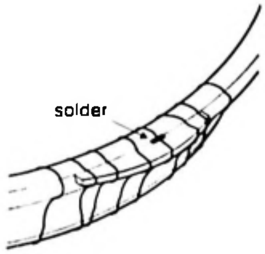
If a thumb piece is needed this can now be fitted. Hold it in position with iron wire and file to shape after soldering, as in Figs 704 and 705. Note that after finishing, the thumb piece becomes a part of the beaded edge and is not noticeably an addition.



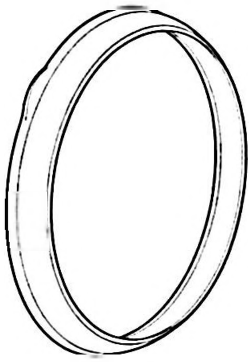
702 The hinge wired into position for soldering



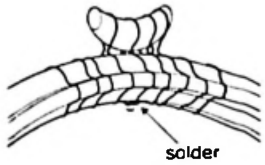
703 Removing the fillet of solder



704 Thumb piece wired into position for soldering

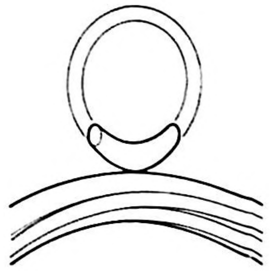


705 Completed thumb piece



706a Pendant wired into position for soldering

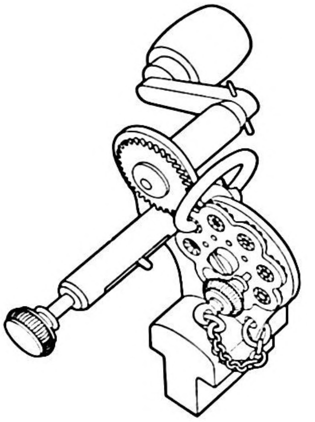
The pendant can be cast complete with mounting pin. Smooth the surface ready for polishing and file flats on the pin to allow access for the solder, as in Fig 706a. Wire in position and solder with easy solder from the inside. The solder will run up the flats of the pin to form a fillet at the junction of the pendant and case, as in Fig 706b. Cut off the surplus length of the pin.



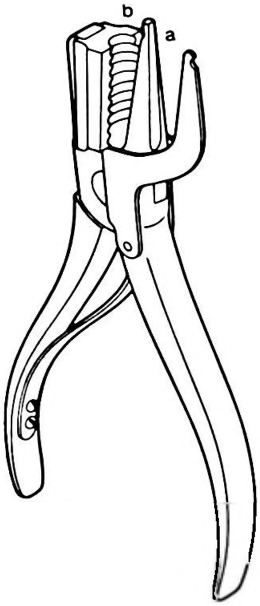
706b Fillet of solder at the base of pendant

The Bow

Form the bow from very hard, drawn wire bent around a former into a circle. The ends are pivoted in a bow pivoter, as Fig 707, and the bow sprung into sinks in the wings of the pendant. The bow is sprung open with the bow pliers, as in Fig 708 at *a*. If it needs tightening use the closing pliers, as at *b*. These have steps of varying radii and will close the bow without distortion.



707 Bow pivoting tool



708 Tool for opening and closing case bows

Hallmarking

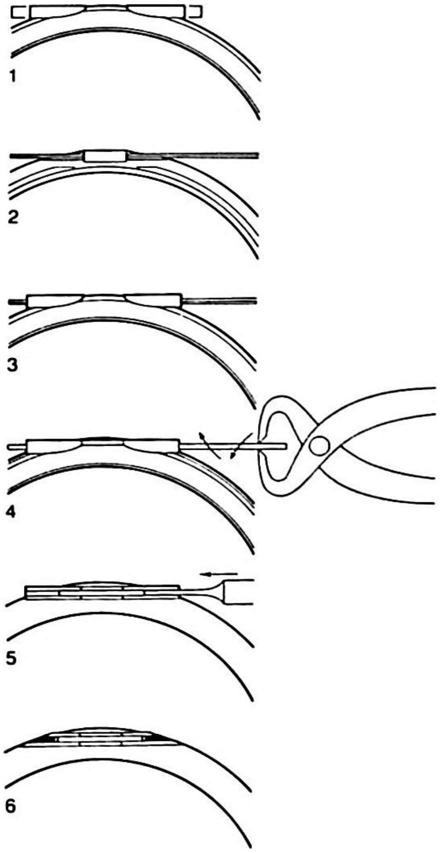
The case is now ready for assaying and punching at the Assay Hall. It must also be marked with the maker's punch where it can easily be seen. Typical hallmarks are shown in Plate VIII (14) for eighteen-carat gold. This is now marked as 0.75.

In England the Goldsmith's Company has a right in Charter to destroy all bad work. This right is rarely invoked but work that is not up to the required quality of workmanship will be rejected. If the case does not come up to the required carat standard the maker may opt for a lower quality mark. This may happen if poor quality solders are used. The case should contain no base metal parts at the time of assay and it is illegal to add any non-detachable base metal after assay.

It is necessary to scrape some metal from the case components for the assay. Mark the parts that may be scraped and instruct the Assay Office in the meaning of the marks. Include a clipping of some part of the material to help to make the weight for the assay. Each component will need punching with the carat quality. Mark the case at the position preferred for the punch. This is important if the case is to be engine-turned.

Pinning the Hinge

The hinge cannot be pinned until the assay is completed. If the case is to be engine-turned this also must be completed before the pinning. Shorten the hinge to the required length and broach the two halves separately from the right-hand side with the hinge uppermost, as shown in Fig 709 at 1, 2 and 3. File the pin from blued-steel wire softened to a grey colour. Make the taper exactly the same as the taper of the broach. Polish quite smooth with the burnisher. Ensure that the pin enters both halves of the hinge to the correct depth. Force the pin into the hinge using the cutters to grip and twist. Check that the action is stiff from the friction of the tight pin, as at 4. Shorten the pin to final length, smear with grease to prevent corrosion and seizure and drive tightly into the hinge with a punch, as at 5. File off the ends and plug with gold wire as at 6. With the case closed rub a worn file along the surface to make smooth and finish with peg-wood and polish. The finished hinge is illustrated in Plate VIII(8).



709 Six stages in finishing the hinge.
1 Shorten tube ends
2 Broach middle
3 Broach bezel
4 Fit pin
5 Shorten pin and drive home
6 Plug ends of tube

Watch Glass

Glasses for watches are no longer made but are still sometimes available as old stock in material shops.

The glass can be moulded by laying a disc between two formers and raising to plasticity in a furnace. Cut the disc 10 per cent larger than required from old photographic plate. The weight of the upper mould on the surplus edge will help pull the glass over the curve without wrinkling. This will leave the glass very slightly thinner at the peak of the curve. When cool, fit true between cork or rubber-faced discs in the lathe. Cut the edge circle with a diamond cutter and break away the surplus edge. Polish the rim with sandstone and water and finish with putty powder on a wood disc.

Acrylic plastic is now universally used for watch glasses. It is easily moulded under hot water with suitable formers. The inner mould is made from brass or aluminium and highly polished. The outer mould is in the form of a ring with rubber stretched over one side. Press the plastic between the mould and the rubber and immerse in boiling water. After about thirty seconds withdraw and cool in cold water. Clamp the shaped plastic between cork or rubber-faced discs in the lathe and trim the edge with a sharp graver supported on the 'T' rest.

The diameter must be a little larger than the diameter of the bezel seat to ensure a tight, dustproof fit. The glass is fitted with the aid of a press tool. The shape is deformed in the tool until it enters the bezel seat. When the screw is released the shape will recover to fit under pressure into the seat. These tools are readily available from tool suppliers.

Plastic glasses for pocket-watches do not scratch in use as might be supposed. They have the merit of being virtually unbreakable and so can safely be used as a transparent cover to reveal and at the same time protect the movement from the curiosity of its owner.

13

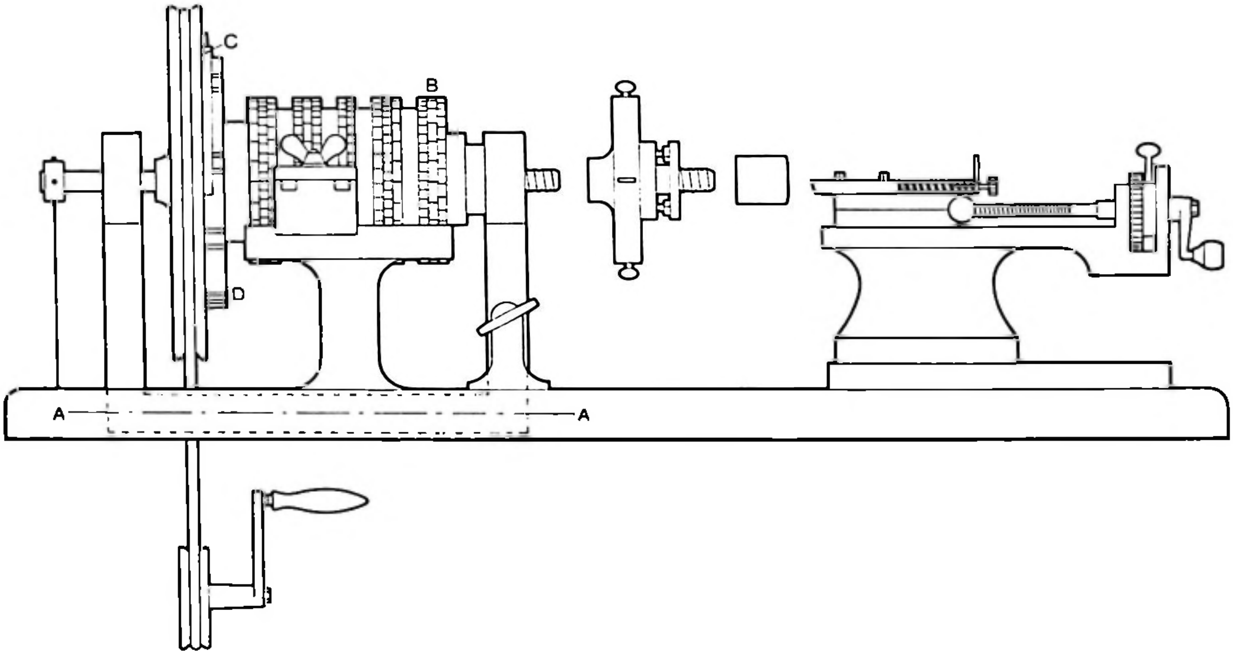
ENGINE-TURNED CASES AND DIALS

Engine-turning as a form of case decoration started in the second half of the eighteenth century. It consisted of simple geometric patterns cut in the surface of the revolving workpiece with a stationary V-shaped cutting tool. The machine used is in the form of a lathe called a rose engine. By the end of the eighteenth century machines for cutting straight lines were also available and these were used principally, in watchmaking, for producing dials. A combination of circular and line work was favoured by Breguet in the early nineteenth century and was used to produce the beautiful dials of his most expensive watches. The complication of the work and the skills required confined the process to the most expensive hand-made watches. With their demise engine-turning declined and the production of suitable machines has virtually ceased.

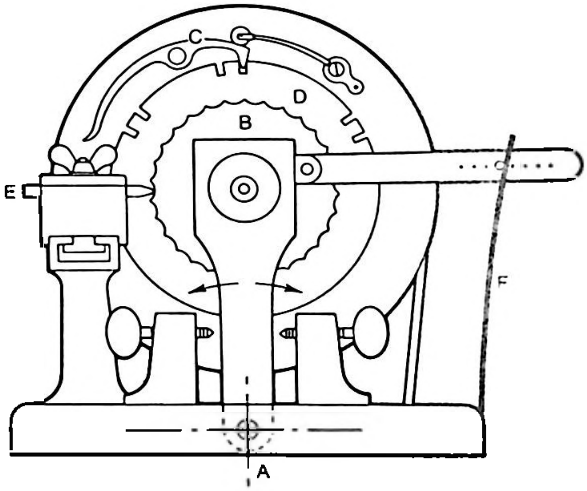
The watchmaker wishing to decorate cases and make dials must now, in all probability, find used machinery and adapt it to his use. The machines must be in good condition and without any wear that could cause slackness in the screws and slides. Irregular action of the machines will show distinctly as a fault in the finished surface of the work and this cannot be erased. Fortunately the machines are simple in design and construction and easily restored to a correct working condition.

The Rose Engine

Fig 710 shows the arrangement of a typical rose engine especially constructed for case and dial work. The belt-driven headstock spindle revolves in the headstock frame which is supported in the bed on two pivots at *A* in Figs 710 and 710a. The rose barrel *B* is fitted loosely to the spindle and locked by the pawl *C* fitted to the spindle pulley and engaging the locking plate *D* of the rose barrel. The headstock frame is urged towards the touch piece *E* by spring *F* so that the selected rose rests upon the tip of the touch piece. As the spindle revolves it also rocks from side to side as the lobes of the waves in the periphery of the rose pass over the touch piece.



710 The rose engine



710a Headstock pivot

The Slide Rest

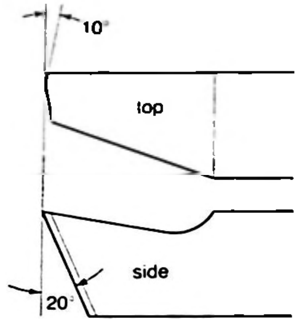
The cutter *a*, in Fig 731, is held in a slide *e*, supported in a slide rest with traverse screw. The depth of the cut is controlled by the rubber *b*, adjusted by screw *c*. During the cut the slide with cutter and rubber is pressed by hand, hard against the work face, to take a full cut to the depth set by the rubber. A full depth cut will cause the rubber to leave a clear rub mark on the work surface. This is called the 'black mark' and if it is not clearly defined and of even width for each cut the pressure is not being constantly applied. The work will show this as an irregular surface with bright streaks. A constant pressure on the slide is by far the most difficult skill to acquire in engine-turning and upon it depends the whole visual quality of the work.

The slide can be adjusted to present the cutter correctly to the work by the tangent screw *d*. The fit of the slide *e* is critical in the slide rest. It must be quite free and smooth in action, but, when oiled for use, without any side-shake in the V-ways. The tangent screw also must be without any slack in the sector thread to avoid backlash in the screw. Other fittings in the slide rest and headstock will be described as they are required.

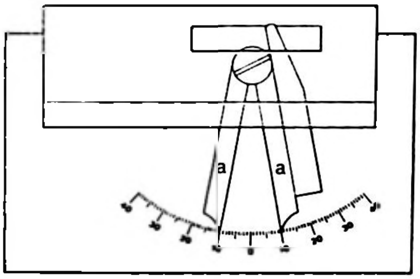
Cutters

The cutting pressures are high when engine-turning gold, and the cutters must be carefully hardened and tempered to avoid chipping. If the cutter does chip, the work cannot be continued and will need to be started again.

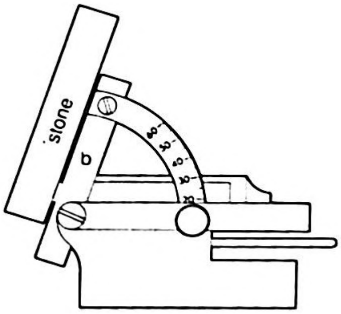
Carbon steel is the best material. File the cutter approximately to the shape illustrated in Fig **711**. Harden in oil and temper to a medium-straw colour. The edges of the cutter are formed in the shape of a broad V and the angles are critical. They are set on a tool called a goniostat, shown in Figs **712** and **712a**. The pivoted arms, *a*, in Fig **712**, are set to 10° each to form the V angle of the tool and the platform *b*, tilted 20° to set the front rake.



711 Cutter angle and front rake



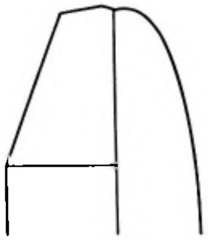
712 Setting the cutter angles



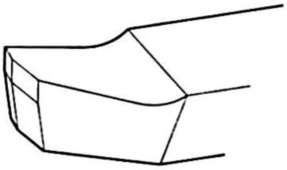
712a Setting the front rake angle to 20°

First smooth the top rake surface of the cutter to remove file or grinding marks. This can be done with an Arkansas slip and oil. This surface will not be touched again. All resharpening is done to the front rake faces.

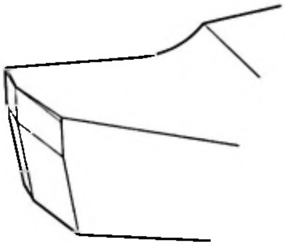
Place the cutter, inverted, on the goniostat. With the oilstone flat on the platform dress the surfaces while the tool is held tight to the angle arm and pushed forward against the stone, as in Fig 712a. The cutting edge closest to the rubber must be kept short to bring the point of the cutter close to the rubber, as in Fig 713. When the surfaces are smooth tip the platform to 18° and finish the surfaces with a well-oiled Arkansas stone. Changing the angle of the platform will confine the work of the Arkansas stone to the upper surfaces at the cutting edges, as in Fig 714. To remove the burrs tip the platform to 85° and reset the angle arms to 10.5°. Lay the tool against the Arkansas stone. Make one, short, upward stroke with the stone and withdraw the tool. Repeat for the second edge. This action will remove the burrs away from the cutting edge and leave a narrow bright edge, as shown in Fig 714a. Sharpened in this way the tool will produce a clean, bright cut that will suit all purposes not requiring a polished finish. When a polished finish is required, as for example with engine-turned cases, the cutter edges should be polished. The sharpening procedure is as before but the final burr is removed with an iron polisher and diamantine. Use the polisher at an angle across the edge while the cutter is lightly pressed against the polisher. The finished cutter will look like that shown in Fig 714a but the small facet at the cutting edges will appear black when turned away from the light. When finished in this way the cutter will produce a brilliant, polished cut especially suitable for case work.



713 Short cutter face close to rubber



714 Finished rake faces



714a The burr removed

Engine-Turning a Case

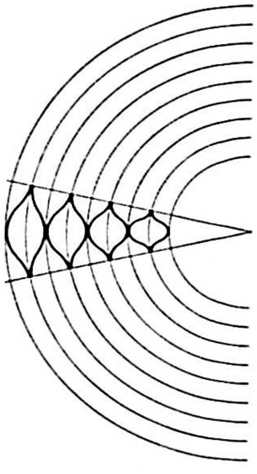
The case must be quite finished, including assaying and hallmarking, before the turning is started. If this is not done the assay marks, although punched on the inside surfaces, will deform the engine-turning on the outer surfaces.

If a polished finish is desired no soldering can be done to any engine-turned surface because the surface cannot afterwards be polished to remove the marks of the fire. If the oxidation from the fire is removed by pickling in acid the surface will turn matt yellow and again cannot be polished. Cases are sometimes seen in which contrast has been introduced by firing and pickling some engine-turned components to contrast with other, polished, engine-turned parts.

The surfaces to be engine-turned must be smooth and matt from the paste used to finish after turning or filing. This is important because the rims and edges of the case parts must be polished by hand methods after engine-turning and this final work must be kept to a minimum. In addition the matt surface will show clearly the black mark from the rubber to indicate that the tool is taking a full cut.

Number of Waves to the Circle

The number of waves to the circle to be cut is a matter of preference or the number available on the roses of the engine. The classic number for a case back is 96. More than 110 will look fussy and the waves will not be clearly defined. Less than 80 will look coarse at the outer edge. It is not necessary to increase the number of waves for smaller case backs. The length of the wave decreases with the diameter and a high number will be too fussy at the centre. The breadth of the wave remains the same for all diameters, see Fig 715.

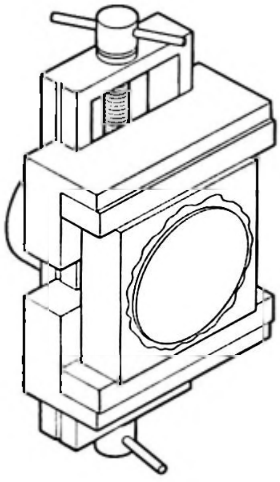


715 The breadth of wave remains constant

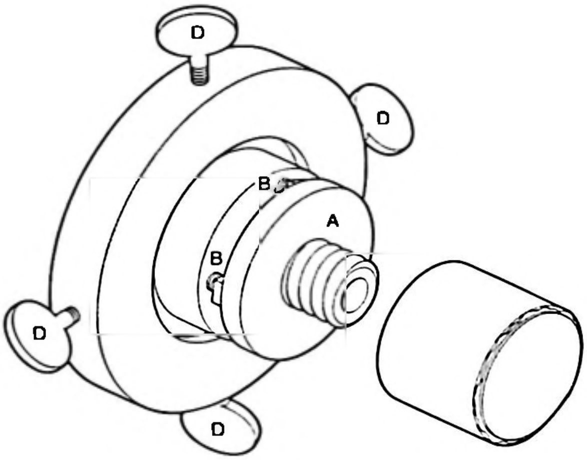
Setting the Cutter

If the cutter is untried it must be verified for finish and depth on scrap material. If the case is gold the cutter must be tried on gold. A cutter that will cut gold cleanly will also cut silver but the reverse is not always true, for silver is softer and can be cut more easily.

The test piece can be cemented to a wood block held in the nose piece vice, shown in Fig 716, or cemented to a wood chuck, as in Fig 717. Note that a truing chuck is used between the wood chuck and the nose piece. Without this it is virtually impossible to bring the work true in the flat and round.



716 Work holding vice

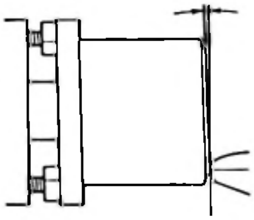


717 Truing chuck

The workpiece is fixed to the carrier plate, *A*, which can be rocked by adjustment of the three screws, *B*, to bring the work square to the spindle. The plate, *C*, can be adjusted for concentricity by four thumb screws, *D*.

Prepare the back of the test piece with water-of-Ayr stone and heat with a lamp to the melting point of the cement. Sealing wax mixed with a very little pork lard to relieve the brittleness will stick firmly without danger of detaching. Clamp the tool into the slide at the centre height of the headstock spindle. This can be checked by rotating the spindle, with belt removed, while the tool is lightly pressed up to the test piece.

If the point of the tool marks a circle and the centre cannot be found by adjusting the traverse, then the cutter must be adjusted for height. The height of the cutter is critical to avoid distortion of the engine-turned pattern.

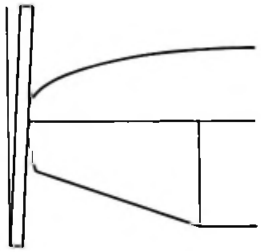


718 Levelling the work face

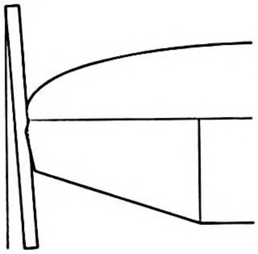
Setting the Work

When satisfied with the height adjust the rubber in advance of the cutter point to prevent the cutter marking the work. Advance the slide so that the rubber touches the work face. The work can now be checked for truth by observing the tip of the rubber as the headstock is turned, as in Fig **718**. It should touch the work face equally for a full turn. If the slide is pushed away on one side only the work surface is not square to the spindle.

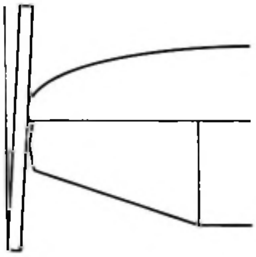
The importance of levelling the work face is seen in Figs **719a, b, c** and **d**. At position **a**, the cutter tip does not reach the work, while at **b**, with the work turned through 180°, the cutter is too deep. Illustrations **c** and d show the exaggeration of this fault if the cutter point is not kept close to the rubber.



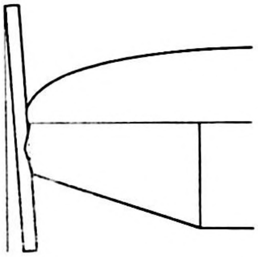
719a Cutter cannot reach work face



719b Cutter too deep into work face

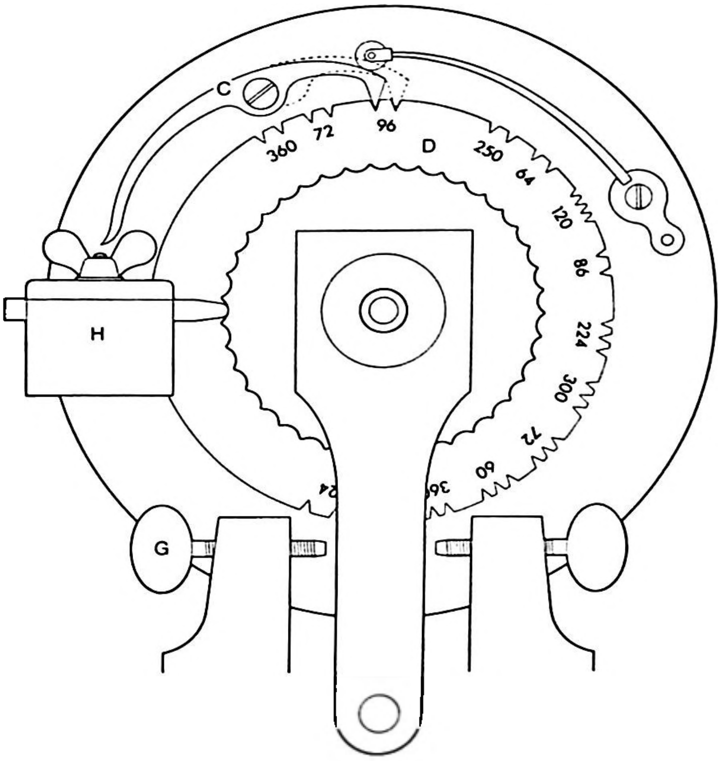


719c Effect of incorrectly shaped cutter

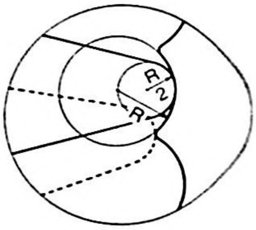


719d Effect of incorrectly shaped cutter

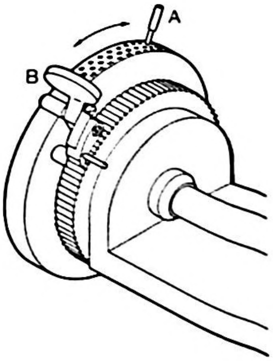
Bring the surface square by adjusting the three levelling screws of the chuck. Lower the screw behind the highest point and draw out the other two by an appropriate amount to lock the carrier plate. If necessary re-centre the work by means of the four centring screws. Finally, ensure that the levelling and centring screws are tight enough to prevent movement of the carrier plate. The leverage of the pressure of the cutting tool will shift the carrier plate if it is at all slack and the work will be spoiled. Refit the driving belt ready for use. Set the locking pawl *C*, in Fig **720**, into one of the two notches marked with the number of waves of the chosen rose. For a case back this may be 96. Clamp the appropriate touch piece *E* into the bracket *H* leaving the tip a few millimeters clear of the waves of the rose. Slacken screw *G* to allow the headstock spring to press the rose into contact with the touch piece. The radius of the tip of the touch piece should be half the radius of the wave. See Fig **720a**.



720 Reversing the wave



720a Detail of touch piece



721 Setting the ratchet stop

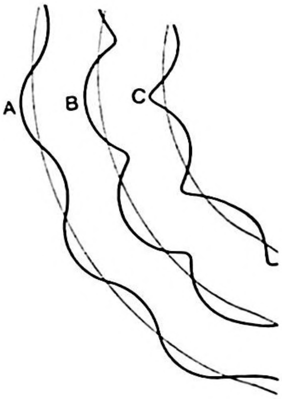
Setting the Slide Rest

Set the slide rest close up to the workpiece so that the cutter can touch the work while the whole of the slide is supported in the V-ways. Set the ratchet stop *A* in Fig 721 to allow the traverse screw to turn approximately two-thirds of the available movement of the ratchet *B*. Traverse the cutter to the chosen position for the first cut. For a test cut this will need to be not less than two-thirds the diameter that the case back will be, so that the wave will be large enough to examine for correct form. Always finally position the cutter by the traverse ratchet to take up back-lash in the screw.

Setting the Headstock

The machine is now set to make the first cut but the setting of the traverse screw ratchet and the curve of the touch piece should be checked first. Start with the locking pawl C set to the top, as in Fig 720, so that it is always conveniently to hand after each full revolution. Turn the headstock slowly against the cutting direction while the cutter is held lightly against the work. The point of the cutter should trace a line, as in Fig 722 at *A*. If the line is as in *B*, with the inner curves too short, the radius of curvature of the tip of the touch piece is too large. If the outer curves are short, as in C, the tip is too small in curvature.

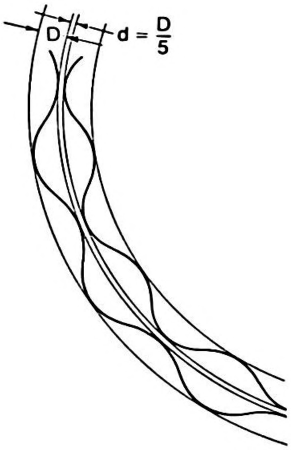
When satisfied with the form of the curves, turn the locking plate *D*, in Fig 720, to lock pawl C into the second notch of the 96 rose.



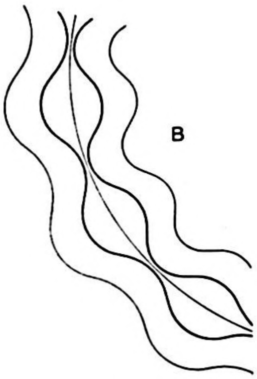
722 Trace of the cutter path

This will have the effect of shifting the touch piece from the bottom of the wave to the crest. The curves of the second cut will now be reversed. Advance the cutter by one full stroke of the traverse ratchet and make a second trace mark alongside the first. The combined effect should be as shown in Fig **723** at *d*, with the two traces separated by a distance equal to approximately one-fifth of the height of the wave. Adjust the position of the traverse ratchet stop pin *A*, in Fig **702**, to achieve the correct separation.

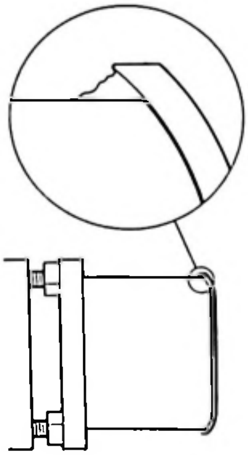
Finally set the depth of the tool by taking two or three light cuts, increasing the depth a little each time until the width of the cut exceeds the height of the wave form. Readjust the locking plate and traverse screw and make the second cut. Fig **724** illustrates the desired result, called barley corn, with the peak of the two cuts exactly in the centre of the waves. If the peak is not in the centre the tool is not vertical to the work face and must be turned by means of the tangent screw, *d*, in Fig **726**. This will alter the depth of the cut which must be reset for a further trial. Observe closely that the black mark is clearly defined on the work face adjacent to the cut, as in Fig **724** at *B*.



723 Correct trace of cutter path



724 Final form of barley corn

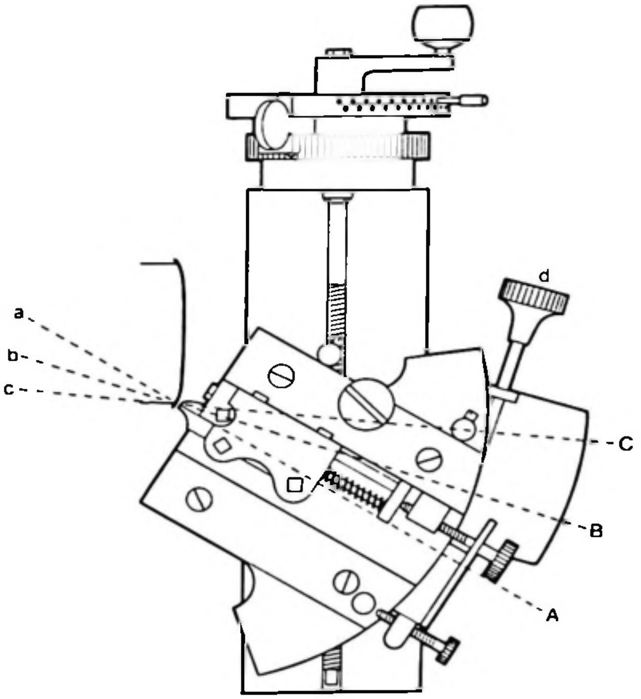


725 Case back cemented to the wood chuck

Machining a Case Back

The machine is now ready to engine-turn a case back of 96 waves of barley-corn pattern. Cement the back to a wood chuck by warming with a lamp until the cement melts freely in contact. Melt cement on to the surface of the chuck turned to fit the contour of the case back. Put the two together and with a little heat knead the chuck into the back to ensure full contact over the whole area. Apply only enough heat to ensure that the cement flows freely into the recess at the edge, as in Fig **725**. Fit to the truing chuck and make true in the flat and round.

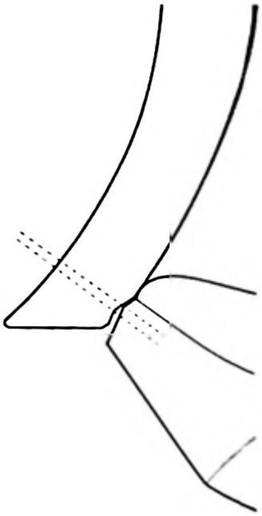
Set the slide rest as shown in Fig **726** where the screw is parallel to the work face, and the cutter is turned to the radial of the mid-part



726 Setting the angle of the cutter holder

of the curve of the case back. The three positions, *a*, *b* and *c*, represent the approximate positions of the cutter at the high and low parts of the curve. The base of the slide rest must be placed on the bed so that the sector can be moved through the positions *a*, *b* and *c*, without displacement of the point of the tool. The sector will, in effect, pivot around the point of the tool. If this is not observed, the width of the barley will vary as the curve is traversed. If the pivot point is within *A*, *B*, *C*, the barley will widen towards the highest part of the curve. If it is within *a*, *b*, *c*, the barley will narrow towards the lowest part of the curve.

Make the first cut with the headstock rose locked clear of the touch piece by screw *G*, in Fig 720, and the cutter aligned with angle *A*, and at the edge of the work, in Fig 726. This will produce a V-shaped groove at the edge of the case back to form a frame for the barley corn. Bring the rose back on to the touch piece and ensure that the lock screw is well clear of the headstock frame. The cutter will need to be traversed back, beyond the edge of the work, and re-advanced to the correct position by using the traverse ratchet. This will take up the back-lash in the screw to ensure that the first wavy cut is correctly spaced. Use the tangent screw to turn the cutter so that it is again radial to the curve. Position the point so that at the lowest part of the wave it is radially clear of the bottom of the V of the plain cut, as in Fig 727. The amount of this radial clearance should be just sufficient to prevent the long edge of the cutter marking the side of the plain cut as the headstock rocks on the waves of the rose.

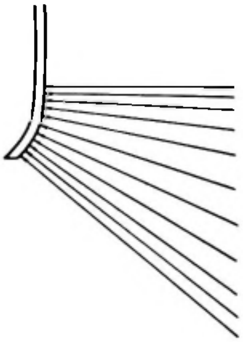


727 Setting the cutter for the first wavy cut

Once the cutter is correctly positioned for the first wavy cut it will be traversed by the correct amount for each succeeding cut with one full stroke of the traverse ratchet. The locking pawl must be engaged with the alternate 96 notch after each cut.

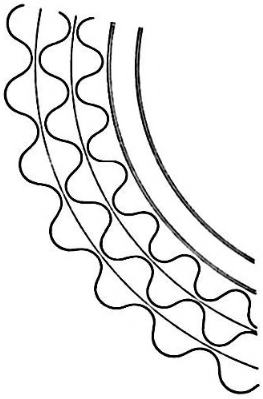
Angular Setting of the Tool

Special attention should be paid to the angular setting of the tool as the curve is rounded. The tangent screw must have some means of indicating the amount it is turned. Numbers on a thimble or notches with a spring click are the usual methods. The screw should always be rotated in the same direction but the amount of rotation will vary as the curve of the work changes. Changes in the amount of rotation should be relatively consistent to avoid sudden angular changes in the reflection from the barley. These will appear as unsightly bright lines as the finished work is moved about to reflect the light.



728 Progressive angles of the cutter holder

It can be seen in Fig 728 that the angle changes rapidly as the smallest radius of curvature is approached and reduces again as the flat of the back is approached. The change in angle must be made progressively before and after the peak of the curve. At some point on the departure from the curve to the flat of the centre of the work the tool will require no further angular displacement. This point should be reached gradually by continuously reducing amounts until the tool is vertical to the flat face.



729 Plain circle for the last cut

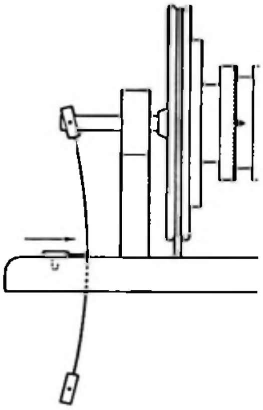
The barley can be continued to the centre of the work but becomes increasingly ill-defined and fussy as the centre is reached. It is therefore better to stop not less than 2 mm from the centre. Lock the headstock away from the touch piece and finish with a plain circle dividing the last cut, as in Fig 729. For illustrations of the completed case back see Plate II.

To avoid errors through distraction that can occur in a busy workshop never leave the machine after setting the controls ready for a cut. Always complete the cut and leave the machine ready for resetting upon return. In this way double setting, which will spoil the work, can be avoided.

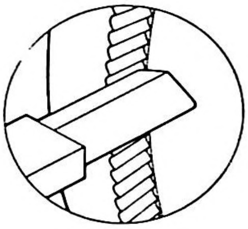
Machining Case Bands

For the bands of the case a rose of 200 waves would be suitable. The radial action of the headstock as used for a case back will not be suitable for the bands unless they are excessively flat as for a thin, dress watch. It is usually more convenient to use an axial or longitudinal movement of the headstock spindle while the frame is locked upright. The conventional roses have waves machined into their sides for this purpose. The spindle has provision for axial movement and is urged against the touch piece by a spring. The principle of the arrangement is shown in Figs 730a and **b**. Exactly the same rules apply to the preparation of the cutter and the form of the curve of the touch piece.

Cement the band to a wood chuck and make true on the truing chuck. Check as described earlier for the shape of the waves and their distance apart. Set the slide rest screw tangential to the curve



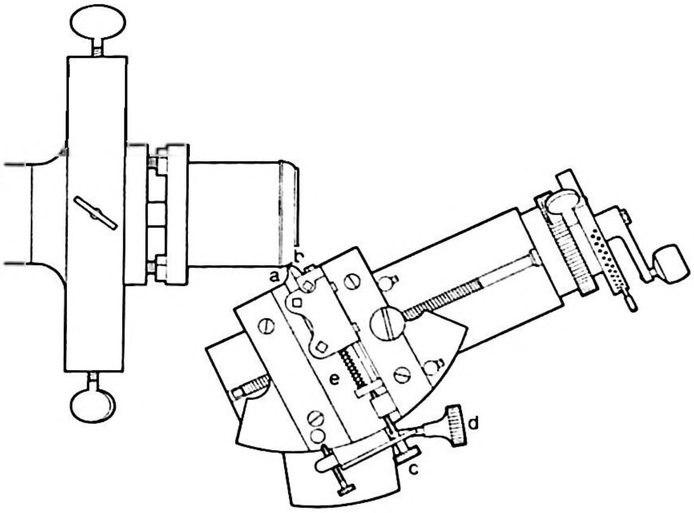
730a Principle of axial movement of the headstock spindle



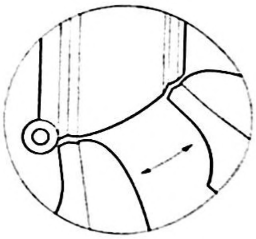
730b Detail of touch piece

of the band, as in Fig **731**, and position the base so that the sector pivots at the point of the tool. All these details are exactly as for radial rose turning. With the tangent screw, set the cutter radial to the band close up to the hinge tube and make the first plain cut to start the barley with a clean edge, as in Fig **731a**. Note that the tool is made especially narrow for this cut and it is important that a trial be made to ensure that the cutter is the minimum width to make a full width cut close up to the beaded edge or the hinge of the band.

Engage the locking pawl with the notches for 200 waves. Unlock the spindle so that it has freedom for axial movement. Engage the touch piece and set the spindle spring to pull the rose into contact. Reset the cutter with the traverse screw and make the first wavy cut. For each succeeding cut reset the locking pawl into the alternative notch for 200 and reset the cutter with the traverse ratchet and tangent screw. The final cut, again, is plain in order to finish the barley cleanly.



731 Setting the cutter holder



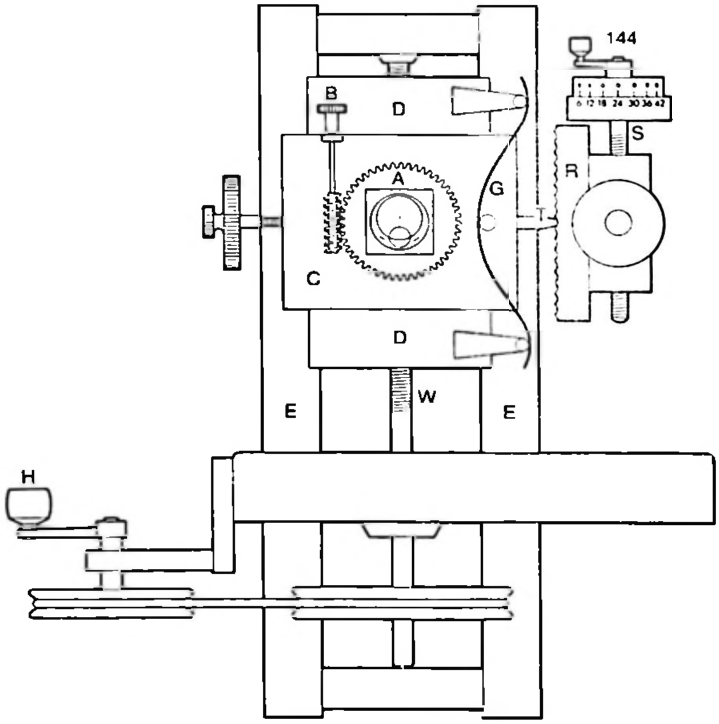
731a First and last cuts for a bezel

In Fig **731a** note that the edge of the case is left square with a sharp corner and the rubber also has a square corner to the acting tip. This enables the rubber to be taken nearly up to the edge of the case to make the final plain cut. The corner can be rounded in the lathe before the final polishing to give a more pleasing appearance to the work. For illustrations of completed bands, see Plate VIII(8).

Straight Line Engine

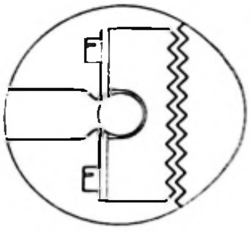
In addition to the circular cutting of the rose engine, straight line work is needed for dials. Some rose engines have adaptors fitting to the nose piece to convert the rotary motion into a straight line motion. A separate engine offers much greater flexibility in use. Fig **732** illustrates the principle of a machine especially constructed for small work such as dial making. This machine is the companion to the rose engine illustrated in Fig **710**. Engine-turning machines were usually constructed in pairs to cover all aspects of the work. The principle of its action is seen in Fig **732**. The workpiece is fixed to the nose piece *A* which can be turned by the tangent screw *B*. The plate *C*, carrying the nose piece, can slide horizontally in the V-ways, *D*, which themselves can slide vertically in the V-ways, *E*.

Fitted into *C* is the touch piece *T* which engages the rack *R*. The rack can be raised and lowered by the calibrated screw *S*. When the handle *H* is turned, assembly *A*, *C* and *D* is raised and lowered by screw *W*; it will also oscillate horizontally under pressure of spring *G* urging touch piece *T* against the serrations of the rack.



732 Principles of the straight line engine

The slide rest is identical to that of the rose engine, and uses the same cutters, set and sharpened in the manner described earlier. Special cutters for both engines will be described as required for the work in hand.



732a Detail of the touch piece and rack

The Vertical Rack

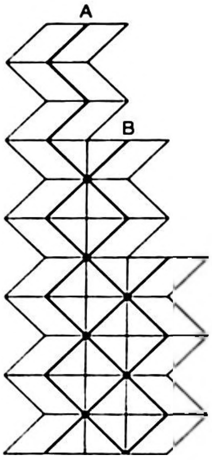
The number of waves per millimeter of vertical travel can be varied by changing the rack for one with the appropriate number of serrations. If a single, chisel-edged touch piece is used, as illustrated, this will serve for all racks. A stronger, and longer-lasting touch piece is made from a length of the rack shown in inset in Fig 732a.

Diamond Pattern

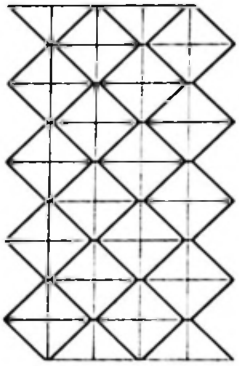
Turning screw *S* by an appropriate amount will alter the position of the rack to reverse the direction of wave pattern of the cut. With a screw and rack of equal pitch turning the screw half a turn and traversing the cutter by half the pitch after the first cut will produce a diamond pattern with the second cut. This is shown in Fig 733 where line *A* is the first cut and *B* the second cut. It is better to traverse the cutter by a little more than half the pitch, as in Fig 734, to avoid vertical separation of the diamonds. The screw pitch is usually coarser than the rack pitch. To find the required angle of turning of rack screw for any rack:

$$\frac{P}{2pr} = \frac{\text{Pitch of screw}}{2 \times \text{pitch of rack}} = \text{turns of rack screw}$$

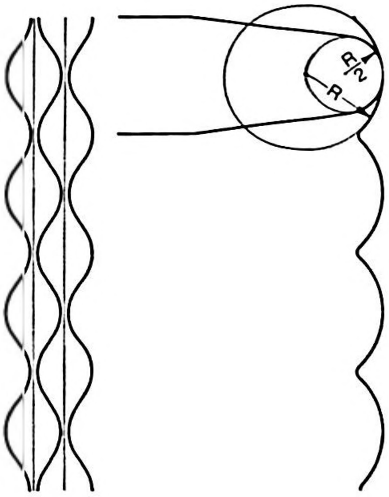
Rows of barley-corn can be produced for small, clock dial panels by using a rack with wave serrations and a touch piece with tip curvature equal to half the curvature of the rack, as in Fig 735.



733 Vertical paths of cutter



734 Spacing the rows to avoid vertical separation



735 Principles of barley-corn pattern

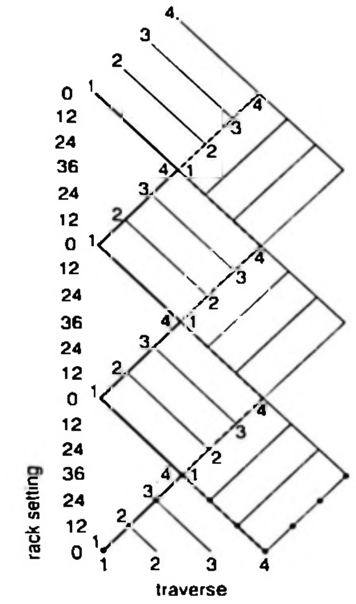
Basketwork Pattern

An effective basketwork pattern, to make a contrast in patterns for seconds dials and other subsidiary dials, can be generated from a coarse rack shifted a quarter pitch for each quarter traverse of the cutter.

The traverse screw and the rack screw will ideally have the same pitch. The graduations of the rack screw setting dial will equal the graduations of the the traverse quadrant. If the screws are not of equal pitch, the required fractions of turns for the basketwork pattern can be calculated from $\frac{p}{4pr}$. The machine illustrated in Fig 732 is calibrated in the old system of twelfths and the rack screw dial is divided into 144 parts, each with a pin hole for a marker pin. The quadrant is equally divided and marked off into 36 parts, represented by holes for the stop pin. The appropriate rack is also marked with the number 36 to indicate its relationship of a quarter pitch of the rack screw.

The pattern will need four shifts of the rack per pitch and four quarter traverses of the cutter. Set the dial of the rack screw to the fixed limit stop at zero. Set marker pins in the numbered holes 12 and 24 and set the adjustable limit stop at 36. Set a stop pin in the traverse quadrant at the number 12 hole. The sequence of movements of the rack and cutter is shown in Fig 736. This consists of a traverse of the cutter by a quarter pitch while the rack is shifted up to the maximum setting and down to the minimum setting by a quarter pitch for each traverse. The rise and fall of the peak of the rack serration for each traverse is shown by the dots. The heavy starting line on the left illustrates the cutter path which, although shifted by the traverse for each cut, remains constant. After the rack has shifted from 0 to 36 in quarter pitches it is returned in quarter pitches to 0. If the pattern is elongated vertically the traverse should be increased. Excessive traverse will elongate the pattern horizontally.

A variety of different patterns can be devised by plotting the path of the rack peaks. But the barley-corn, diamond and basketwork patterns are most suited to watch dials which require variations of surface rather than decoration.

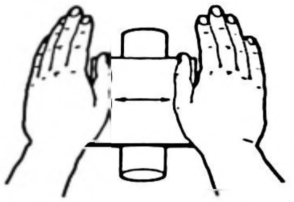


736 Sequence of cutter settings for basket pattern

Dial Making

Preparing the Dial Plate

Silver or gold is the usual material for the dial. Silver will produce a better contrast than gold after the final finishing treatment. Prepare a square of the chosen material by laying on a flat surface and raising to a dull red heat to release any rolling stresses. Allow to cool slowly and clean both sides with water-of-Ayr stone to produce an overall circular grain. This will help to observe scribed lines which will be the boundaries for the engine-turned patterns and at the same time make the black mark from the rubber prominent. The plate will need to be larger than the finished dial to give support to the rubber when engine-turning close to the edge. It must be quite flat to ensure a uniform depth of cut over the whole surface, and of sufficient thickness to allow for recessing the seconds dials, etc., into the surface. The dials of the watches illustrated are 1 mm thick. If the metal has been excessively rolled it may be bowed by the rolling stresses. Check with a straight edge across the surface from side to side and from corner to corner. A bow can be removed by rolling the plate over a piece of wood dowel or similar roller. Apply hand pressure at the high points while rolling, as shown in Fig 737.

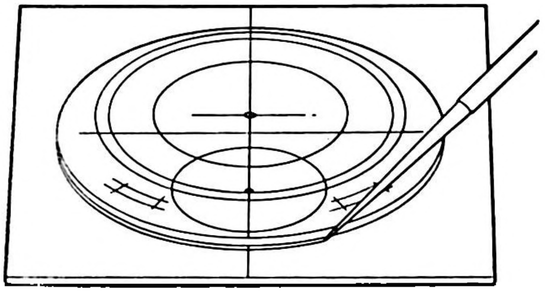


737 Flattening the dial plate

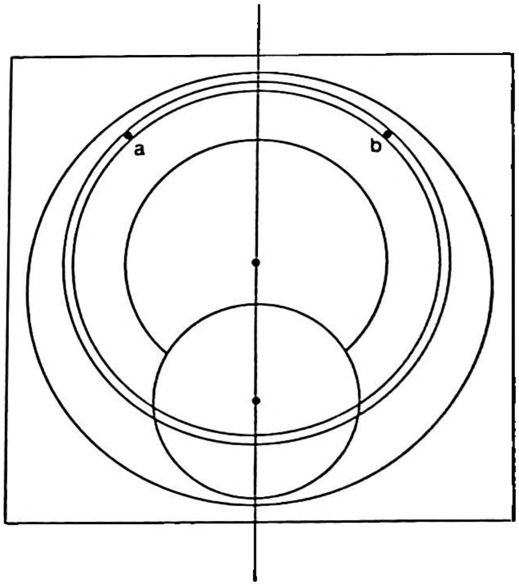
Marking Out the Dial

The design of the dial will have been completed when laying out the components of the movement, which involves making a temporary brass dial. Scribe a fine line across the plate and carefully align the scribed centre line of the brass dial with the line on the plate, as in Fig 738. Clamp the two together and drill through the holes for the hands. Use the same sized drills as were used for the brass dial to ensure concentricity in the holes. Scribe a circle close up to the edge of the brass dial to indicate the required limits of the engine-turning. Unclamp and put the brass dial behind the plate pinning it into place through the drillings with brass pins. Scribe a deep line around the edge. This line will be used when cutting the dial out of the square plate on completion of the engine-turning.

The circles for the minutes can now be scribed with a compass centred on the hole for the minute-hand arbor. For a dial of the design shown in Plate II the precise radii will be determined by the holes for the two sectors shown in Fig 739, *a* and *b*.

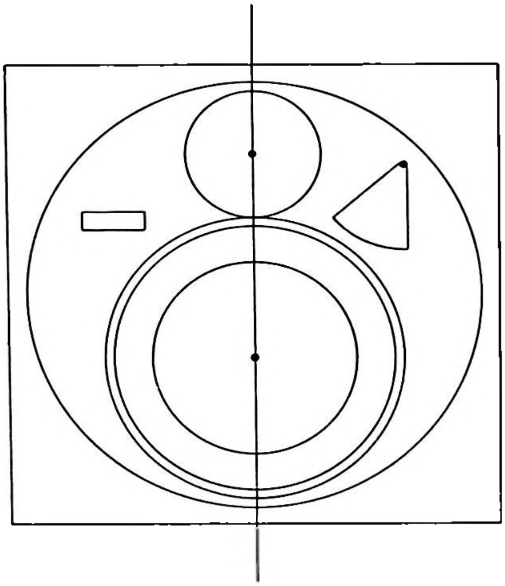


738 Marking out the dial diameter



739 Marking out the dial plan

For the dial of Fig 740 the diameter will be determined by the diameter of the seconds dial. All diameters will have been approximately determined when making the brass dial. But when marking out the new dial, close attention must be given to the final diameters. If, for example, in Fig 740 the edge of the minute circle were brought too near the edge of the dial, the seconds dial would be reduced by twice the error. The seconds dial will not have a border but the minute dial will, and allowance must be made for this. The space between the edge of the seconds dial, without border, and the edge of the dial, must be the same as the space between the minute circle with border, and the opposite edge of the dial, to achieve the desired effect. Move the compass from hole to hole making light trial marks until the best diameters are found, and then heavily scribe the marks. Scribe also the inner and outer borders of the hour chapter ring and the zones for the signature.



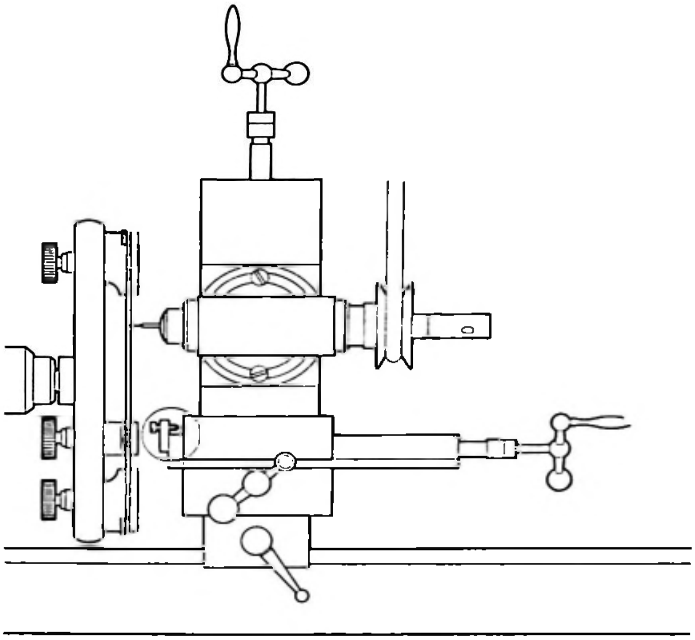
740 Marking out the dial plan

Drilling the Divisions

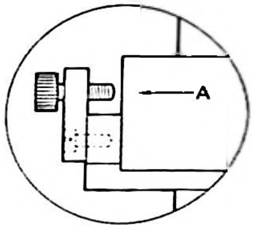
The dial is now ready for drilling the markings within the circles for the minutes. Fit up the dial plate on the mandrel of the lathe, and make concentric with the minute circles. Fit up the drilling quill, as in Fig **741**, and with the vertical and traverse screws carefully locate the point of a true drill on the centre line, midway between the minute circles with the index engaged. Verify the position by turning the dial 180° to bring the opposite end of the centre line under the point of the drill again with the index engaged. The alignment will be exact if the circles are concentric. Ideally, the top slide should be fitted with a stop screw to regulate the depth of the drillings, as in Fig **741a** inset. New lathes are not supplied with this very useful accessory which can easily be made.

Smear the surface to be drilled with thin oil to prevent the drill biting and make sixty drillings for the minutes to a depth sufficient to reproduce the full diameter of the drill, as in Fig 741a. The diameter of the drill will depend upon the diameter of the minute circle. For the watch illustrated in Plate II, 0.5 mm is used. For a smaller circle, as in Plate V, 0.4 mm is suitable.

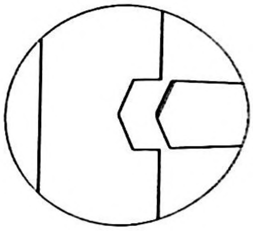
Change the drill for a larger size and enlarge the five-minute markings for the hours. If the minute circle is to be cut through to recess the seconds dial, as in Fig 739, the drillings must be made appropriately deeper within the seconds circle.



741 Making the minute divisions with the drilling quill



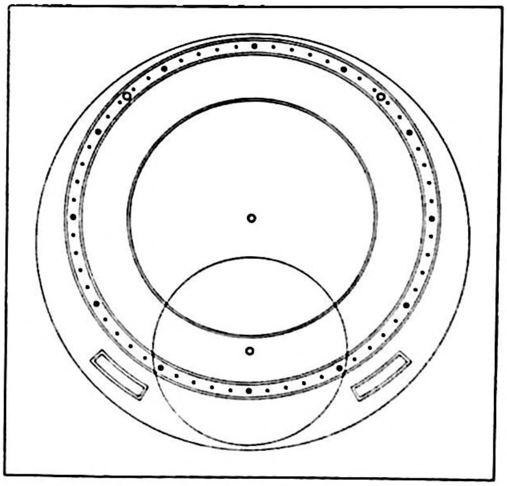
741a Detail of depth stop



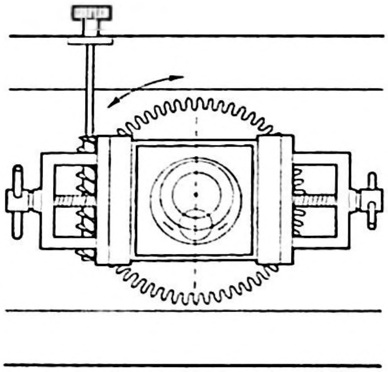
741b Detail of drilling

Machining the Centre Zone

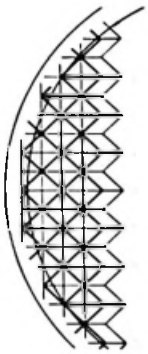
On completion of the drilling the dial will look as in Fig **742** and is ready for engine-turning. Cement the plate to a flat wood block held in the nose piece vice, as in Fig **743**, and with the tangent screw, set the centre line upright. Check this with the cutter point at each end of the line. Set up the machine with a rack of about eighteen serrations per centimeter, and set up the traverse quadrant stop and rack screw as appropriate. Make trial cuts in the unwanted corners of the dial to check the spacing and depth of the cuts. Start the cuts at the left edge of the centre zone of the dial. Make the first cut on the



742 Dial ready for engine-turning



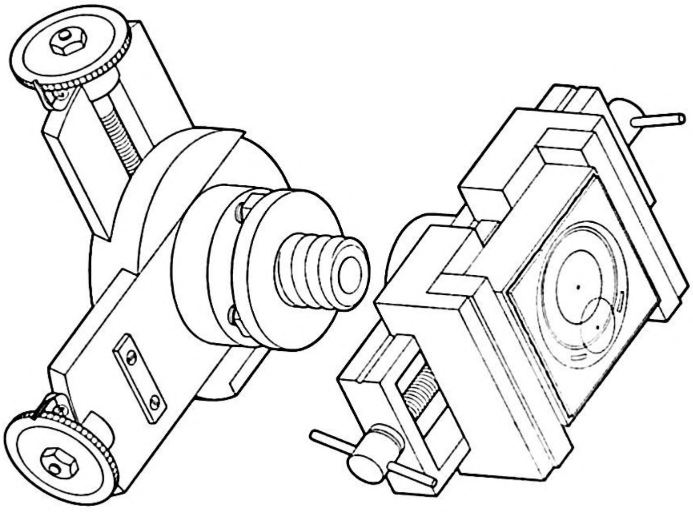
743 Vertical setting with the tangent screw



744 Start and finish the cuts within the boundary circles

boundary circle and within the chapter ring circle, as in Fig **744**. Note that the inner border line must be crossed at the beginning and end of each cut but the cutter is withdrawn within the circle for the inner edge of the chapter ring. Continue the pattern until the whole of the inner zone is completed.

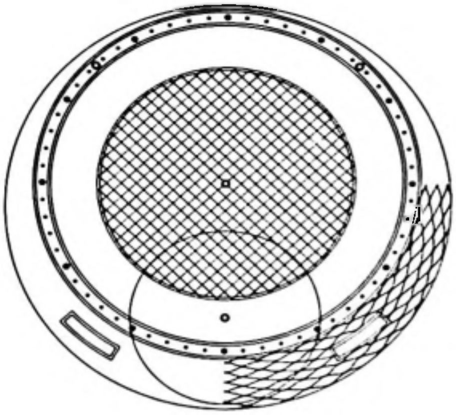
Machining the Outer Zone
Transfer the vice to the nose piece of the centring slide of the rose engine, as in Fig **745**, and make the circles of the minutes concentric and square to the spindle. Fit up the engine with appropriate touch piece and set the locking pawl to the chosen rose, and engine-turn the outer zone. For the dial shown in Plate II a rose of 96 waves was used. For that of Plate V, 200 was more suitable for the dial proportions.



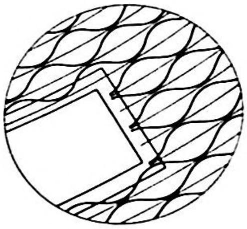
745 Centring slide

Start the cuts on the right edge of the chapter ring so that the rubber does not pass over the minute divisions. Again the first cut must be within the border circle but not touching the minute ring circle, as in Fig **746**. Note that the circle for the seconds can be ignored but the cutter must be withdrawn at the signature zones, as in Figs **746** and **746a**. Here again the outer line is crossed with the cutter but the inner line must not be crossed. Excepting that it is not necessary to change the cutter angle the process is similar to engine-turning a case back as earlier described.

Ensure that the cutting is taken over the circle of the full diameter of the dial. Full circles cannot be cut at the upper edge because the minute circle is not central to the plate. Withdraw the cutter as the full diameter circle is crossed to prevent the rubber passing over the edge and digging the cutter into the plate. If this happens the plate could detach and the work will be spoiled.



746 Lift the cutter to preserve the bordered areas

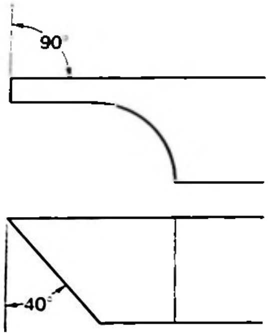


746a Detail of bordered area

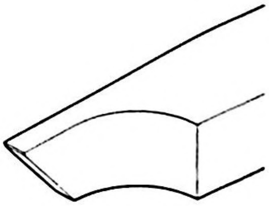
Machining the Boundary Circles

When the outer zone is completed the ratchet-bottomed circles for the borders can be cut with a narrow chisel-shaped cutter, as shown in Fig **747**. Set the cutter with a 90° front edge and a 40° rake. After rubbing flat on the oilstone to ensure sharp side edges, finish the front edge with an Arkansas stone to remove the burrs and strengthen the tip, as in Fig **747a**. The width of the cutter is equal to the space between the chapter circle and border circle. Use the goniostat to set the angles with the angle arms at zero and the platform at 40°. Remove the burr with the platform at 85° by a single light stroke of the Arkansas stone. It is important that the side edges are very sharp to avoid throwing up burrs that cannot satisfactorily be removed after the cut is completed.

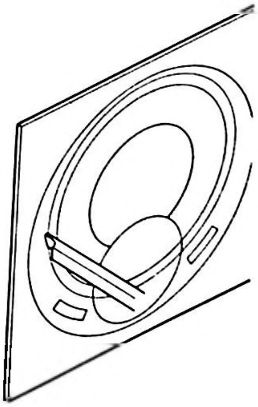
Set up the machine for axial use with a side rose of 300 waves. Disengage the traverse ratchet, fit the cutter into the slide and withdraw the rubber which is not required for this work. Traverse the cutter to bring the right-hand edge up to the circle for the minutes, as in Fig **748**. Set the slide stop screw to control the depth of the cutter and cut a groove about 0.2 mm deep, as in Fig **749**.



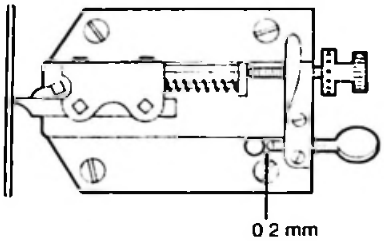
747 Chisel cutter



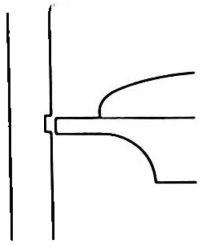
747a Burr removed from cutting edge



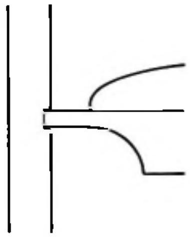
748 Set the cutter up to the circle



749 Screw to set cutter depth



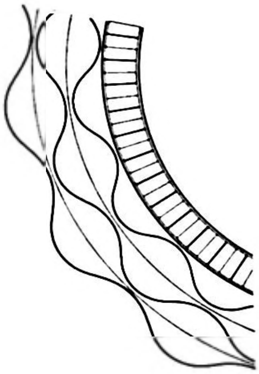
750 Widening the groove



750a Centring the cutter

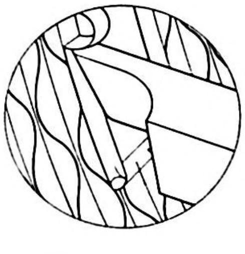
Traverse the cutter by a very small amount, just sufficient to ensure freedom of the sides of the cutter. Make a second cut, as in Fig **750**, and reposition the tool to the centre of the widened groove, as in Fig **750a**.

The groove is now ready for the ratchet cut. Release the headstock spindle to allow axial movement. Engage the touch piece for 300 and tension the spindle spring, as earlier described for engine-turned bands. Giving axial freedom to the spindle will bring the work closer to the cutter. Reset the cutter stop screw to bring the cutter into contact with the bottom of the groove. Press the slide hard on to the cutter stop as the headstock rotates. In oscillating to and from the fixed cutter a form of ratchet will be cut into the bottom of the groove, as shown in Fig **751**. The swarf from this cut must be continuous for the whole length of the cut. Swarf in the form of small chips indicates a discontinuous cut and can be corrected by a further, deeper cut.



751 Finished border zone

Repeat the process for all other border circles, and finish the curved edges of the signature zones with a round-faced cutter, as in Fig 752. The radial ends of the zones will be finished later, with the same cutter, in the straight line engine.



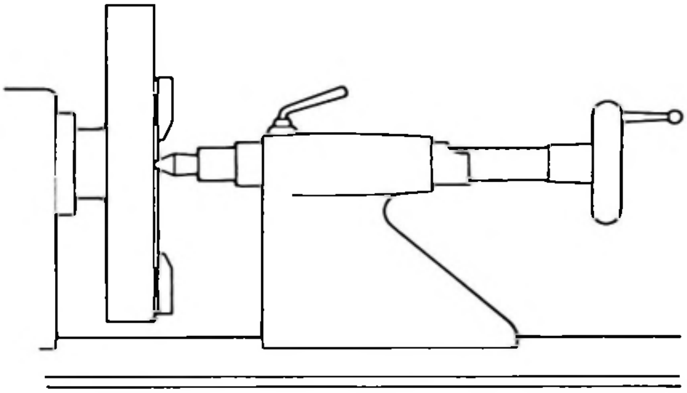
752 Finishing the reserve borders

Machining the Recesses

The dial is now ready for recessing the seconds dial and any sectors that may be included in the design. The seconds dial can be recessed in the rose engine if the slide has provision for a drive to the traverse screw. The sectors can be recessed in the straight line engine but the work would need to be transferred to the rose engine to cut the curved edge. Both operations can be completed more conveniently in the lathe.

Seconds Circle

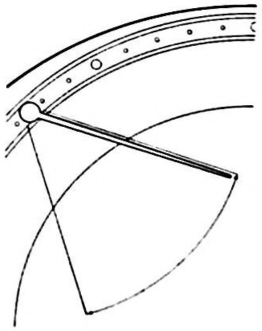
Remove the dial from the wood block and wash off the cement with solvent. Centre the seconds with the tailstock centre and clamp the plate on to the face plate, as in Fig **753**. Turn the recess with a sharp, pointed cutter lubricated with thin oil. The required diameter is indicated by the compass arcs still visible on the chapter ring. A depth of 0.4 mm will give freedom to fit the seconds hand level with the surface of the dial. Make several light cuts starting at a little smaller diameter than the required final diameter and work towards the centre. At 0.35 mm depth set the cutter point up to the full diameter. Advance to the full depth and make the final cut to the centre. This method will ensure that the cutter pressure is always away from the edge of the recess to prevent raising a burr which could not be removed. Clamping the plate flat to the face plate while turning will prevent tool chatter and possible distortion of the surface of the recess. Smooth the surface with water-of-Ayre stone, re-scribe the arcs for the minute ring and boundaries and the recess is ready for engine-turning.



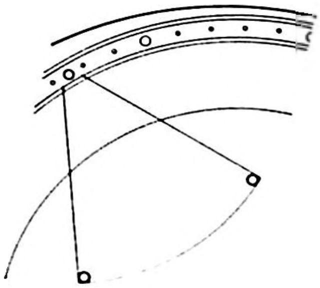
753 Centring the seconds hole

Sectors

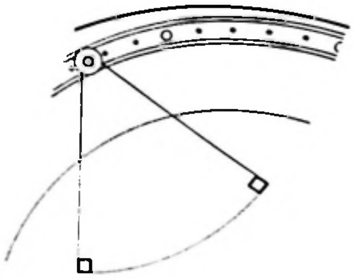
The size and position of the sectors can be taken from the temporary dial. Fit a hand to the sector arbor and mark the limits of movement of the hand on the temporary dial surface with a sharp point, as in Fig **754a**. With a compass scribe an arc to join the two marks. Scribe the boundaries with a sharp point and allow freedom for the hand by extending the boundary beyond the limit marks. Note that the lines do not intersect at the centre of the motion of the hand but are parallel to the edges of the hand at the upper and lower limits. Drill holes 1 mm in each corner to touch the lines, as shown in Fig **754b**. Pin the temporary dial to the new dial plate and drill through the holes. Scribe the boundary lines from the edges of the holes and file the holes square up to the lines, as in Fig **754c**. Cut a sink 0.5 mm deep and extending in diameter to touch the inner and outer boundaries of the minute circle, as in Fig **754c**. The sector is now ready to be recessed.



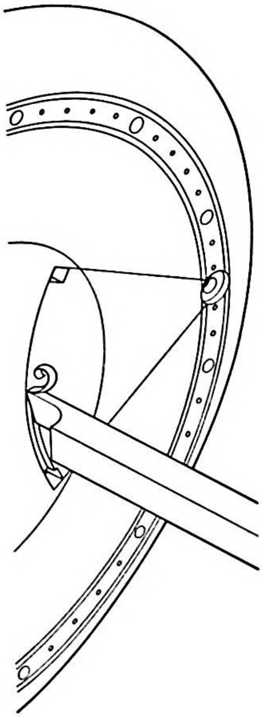
754a Marking the limits of the sector



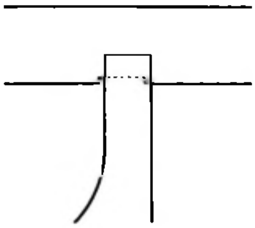
754b Drilled swarf holes



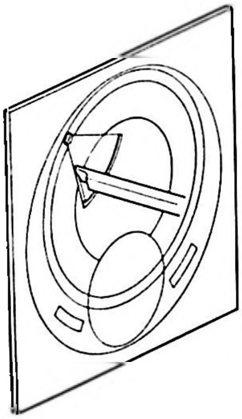
754c Finished swarf holes



755a First cut for the sector



755b Widening the groove

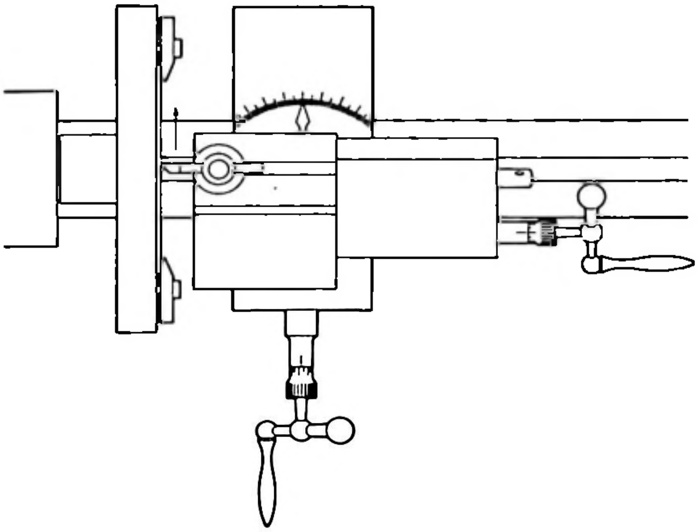


756 Progressive radial cuts for the sector

To cut the recess in the straight line engine it must first be prepared in the rose engine. Cement the dial to a wood block and centre the sector hole with the spindle. Prepare a chisel-shaped cutter, as in Fig **747**, but of a width equal to the narrowest part of the boundary lines of the sector. Set the cutter stop screw with the cutter touching the surface of the dial and with one edge up to the arc of the sector, as in Fig **755a**. Turn the spindle to bring the edge of the cutter into the lower hole and take a single cut to the depth of the engine-turning of the centre zone. The swarf will detach at the upper hole. Now traverse the cutter so that the edge is just clear of the outer edge of the arc of the cut, as in Fig **755b**. The cuts can now be continued to the required depth of 0.4 mm without danger of raising a burr at the edge.

Transfer the dial to the straight line engine and set the centre of the sector hole at the centre of the nose piece. Turn the dial with the tangent screw to bring a boundary line vertical at the left, as in Fig **756**. Set the cutter in position and make the first cut to the depth of the engine-turning as previously described. Turn the sector screw to give clearance to the left edge of the cutter and complete the cuts to the full depth. Repeat the process at the other edge and finally cut away the centre. Note that the cutter is taken through the narrowest part of the boundary into the circular recess. The cutter must be advanced a very little for each cut. Several cuts are required to reach the full depth. If the cuts are deep the surface of the silver will tear and leave a scar which may be too deep to erase. Smooth the surface of the recess with water-of-Ayre stone ready for engine-turning.

The recess can be cut in the lathe by clamping the dial to the face plate and rotating the work about the arbor hole using a worm and wheel dividing mechanism. The same cutting method is used but the cutter is held in the slide rest and advanced by the cross-slide screw, as in Fig 757.



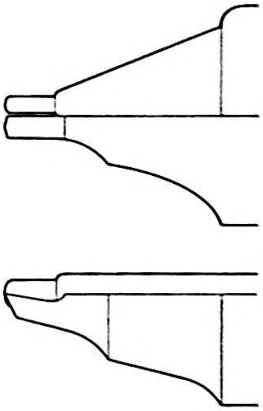
757 Recessing the sectors in the lathe

Mark the boundary lines in the recesses as a guide to ensuring a sufficient area is covered by the engine-turning. The depth of the tool below the cutting edge and the width of the rubber will prevent the continuation of the cuts to the edges of the recesses. The circle for the seconds markings will cover the border of the recess and so the cuts need not be continued to the edge. The plate for the sector markings will cover the border of the curve of the sector recess. The cutter must be brought up as close as possible to the straight edges. If a diamond pattern is chosen, introduce contrast by using a rack of finer pitch than that used for the centre zone. If the basketwork pattern is used greater concentration is required to avoid butting the rubber against the edges of the recess and raising a burr that cannot be erased.

Setting the Machine

Set the dial upright in the straight line engine and fit up the required rack and quadrant stop pin. If basketwork is chosen set two guide pins in the rack screw dial and set the limit stops for maximum rise and fall of the rack. For diamond or barley-corn, only the maximum and minimum stops are required.

Prepare a cutter and rubber of the smallest possible sizes to allow the point to reach close up to the edges. Fig 758 gives suitable dimensions. Note that the face of the rubber must be curved to prevent the edges scraping the surface. The smallest irregularity of

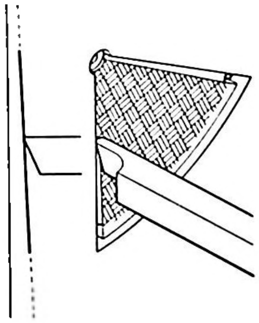


758 Rubber and cutter for small recesses

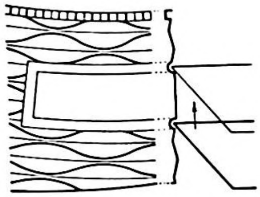
the surface will alter the depth of the cut and be reproduced in the work. Make trial cuts at the surplus corner of the plate to check the depth of cut and quality of the pattern.

Cutting the Borders

When the work is completed change the tool for the curved-face tool shown in Fig 752 and, with the edges of the sectors vertical, make a cut to clear the edges of the surface, as in Fig 759. Tip the dial slightly for this final operation and the cut groove will narrow towards the circular recess in sympathy with the edges of the sector. Note that the pattern does not extend to the circular recess at the pivot hole which was cut deeper than the sector recess. Before removing the dial from the engine finish the ends of the signature zones with the curved-edge tool. Take the tool into the deepest part of the inner border groove, and withdraw at the deepest part of the outer groove, as in Fig 760. The dial must now be returned to the rose engine for re-cutting the borders of the minute ring within the seconds circle.



759 Finishing the sectors

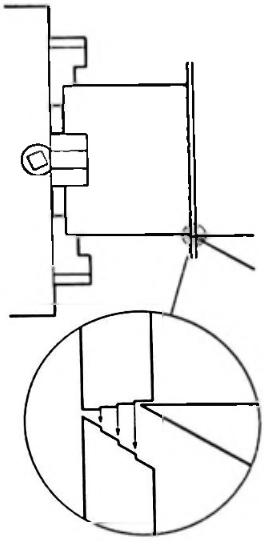


760 Radial finishing cut for the reserve borders

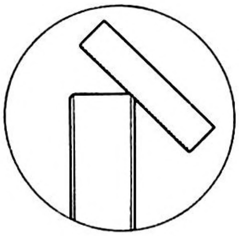
Cutting Out the Dial

To cut the dial out of the plate cement face down on a wood chuck, as near as is practicable concentric with the scribed circle now visible on the reverse. Set the wood in the independent jaw chuck in the lathe and make the scribed circle concentric. Cut away the border with a long, pointed tool taking light cuts away from the circle, as in Fig 761. To avoid heating the dial the cutter must be very sharp and drawn away from the circle to give a large clearance in the initial stages.

When the border detaches make a final finishing cut to the edge of the dial and remove the burr from the corner with a file. Remove the dial from the wood chuck and wash clean in solvent. Scrub with a stiff bristle brush using a circular motion to remove all traces of cement from the corners. Clean out the holes with a broach. With a file carefully remove the burr from the front corner of the edge as shown in Fig 762.



761 Clearing away the edge for cutting out



762 Removing the burr from the edge corners

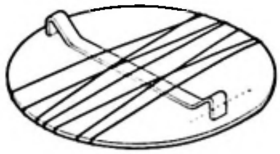
Dial Feet

Edge Screws

If the dial is to be secured by screws from the side or back of the movement, dial feet will be needed. Place the dial in position in the movement recess and mark at the edge for a side screw and through the dial-foot hole for a plate screw. For a side fixing, cut a strip from the discarded border of the dial, bend it to shape and secure in position with thin, iron, binding wire, as shown in Fig 763.

Rest the dial on a clean, iron wire pad and secure the ends of the strip with easy melting gold solder. Play the flame over the whole area of the dial to avoid distortions that could shift the positions of the ends of the strip. When cool, remove the wire and wash the dial in a hot solution of twenty parts water to one part sulphuric acid. This will remove the fire stains and the remains of the borax flux.

Cut off the surplus height of the feet as indicated by the dashed line in Fig 763. Fit the dial on to the movement and drill through the dial screw holes. Thread the movement holes and fit screws, as shown in Fig 764.

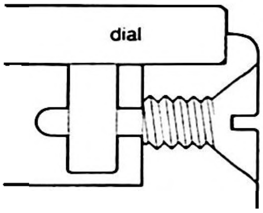


763 Dial feet secured with iron for soldering

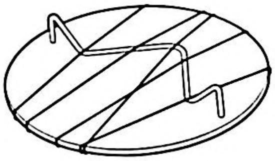
Plate Screws

For a plate screw fixing, make the feet of gold wire set in position as in Fig 765. Secure the ends of the wire with easy melting gold solder and wash as before in diluted sulphuric acid. Cut the wires to a generous length and with the dial on the movement, mark the feet for the fixing screw slot, as in Fig 766. Finally cut the wire to length. Note that the screw heads are shaped to draw the dial up to the plate when the screw is locked. These screws are sometimes flat-headed and arranged to secure the dial to the plate when drawn up as for unscrewing. This is not good practice and can result in damage to the dial-foot slot.

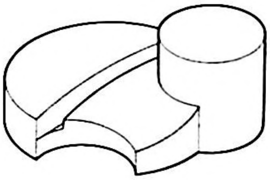
The dial of the watch shown in Plate II is secured by a single screw through the inner zone.



764 Dial-foot screw



765 Dial pins secured with iron wire for soldering

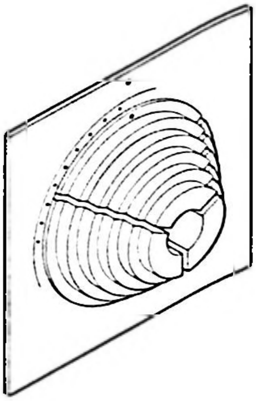


766 Dial foot plate screw

Seconds Circle and Sector Index Plate

Seconds Circle

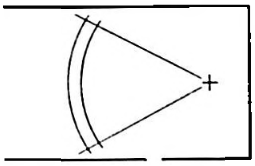
Cut a hole in a piece of hard-rolled silver sheet 0.5 mm thick. Open the hole to fit a step collet of two-thirds the diameter of the required seconds circle, as in Fig 767. Locate the silver with a mark against a corresponding mark on the collet. Turn away the unwanted border and reduce the circle so that it almost fits the recess in the dial. The locating marks will help the silver to the same setting on the collet after each trial.



767 Preparing the seconds circle

Catch a light circle on the face with the point of the graver at the required radius for the division drillings. Set up the drilling quill, as in Fig 741, and make the drillings of 0.25 mm opened to 0.5 mm for the five-second marks.

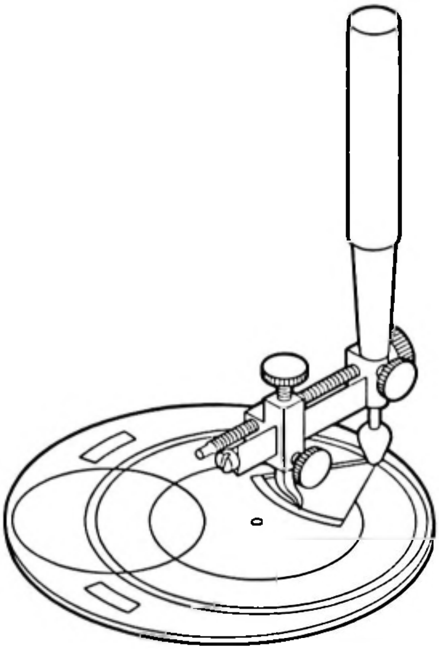
With a sharp-pointed graver part the circle away from the collet. Fit the circle into a hollow step chuck and take a finishing cut from the inner edge. The completed ring should snap into the dial recess and need no further fixing. If it is preferred to secure the circle with screws drill two 0.3 mm holes through two opposite five-second marks. Fit the circle correctly orientated in the recess and drill through the holes. Thread the holes 0.4 mm. Open the dial holes to accept the screws and sink the heads flush with the back of the dial. Blue the screws before final fitting.



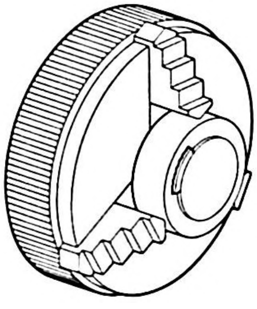
768 Marking out a sector scale

Sector Plate

For the sector index plate, strike two arcs of circles of appropriate radii and cut out the plate with a fine saw, as shown in Fig 768. File all edges smooth and carefully reduce the length to fit the plate into the recess. From the arbor hole of the sector strike an arc near the inner edge divisions, as in Fig 769. If the division is simple, as for a winding indicator, the arc can be divided with fine-pointed dividers and the marks drilled as for the seconds circle. Complex divisions will need to be done with a dividing head in the lathe.



769 Striking the arc for the sector divisions



770 Sector scales cemented to concentric plate

Turn a brass blank to support the plate, which is cemented into position, as in Fig 770, ready for drilling with the quill. Secure the plate to the dial with screws threaded into two of the divisions. Sink the screw heads flush with the back of the dial as for the seconds circle screws.

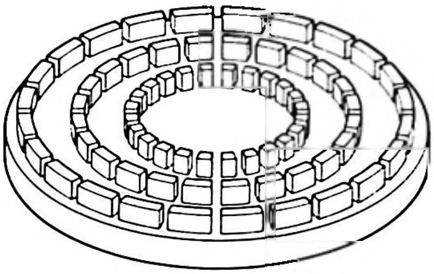
Engraving

The dial is now ready for engraving, but unless the watchmaker has the necessary skill acquired from years of experience he should put the work out to a practised engraver. Even then a sample of work should be commissioned before entrusting the work to an unknown source. The work can be done with a pantograph engraving machine, but will need considerable skill afterwards with a sharp graver to eliminate the mechanical and ungraceful effect that such machines are capable of producing.

Finishing the Dial

Bleaching the Surface

Wash the dial in solvent to dissolve any remaining traces of cement. Do this most carefully with a soft brush to reach into the corners of



771 Dial supporting plate

the engine-turned areas. Wash again with soap and water. Dry by patting with a clean cloth or tissue paper. Support the dial face-up and flat ensuring that the feet are not touching the support. The plate shown in Fig 771 is turned from a disc of brass and will support any sized dial without resting on the feet.

Shade the dial from direct light. With a blow torch played uniformly over the surface of the dial raise it to a dull red heat. Allow to cool and then place in a dilute solution of hot sulphuric acid mixed in the ratio of twenty parts of water to one of acid. Hold the temperature of the acid to about 90 °C.

The heat from the torch will discolour the dial by burning the impurities in the surface of the metal. The acid will clear the discoloration by dissolving the oxides to expose a pure silver surface. If the dial is not completely clean, wash away the acid, dry the surface and repeat the process.

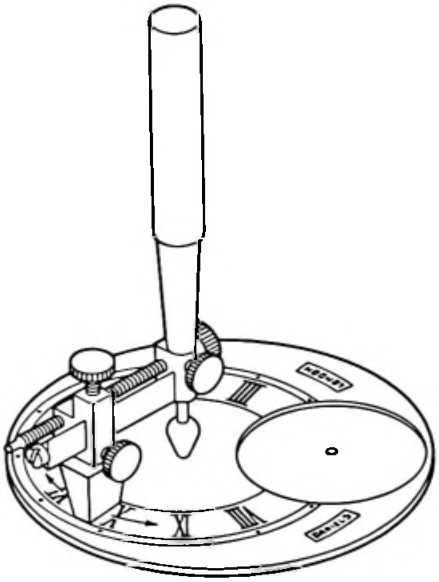
A greater heat from the torch would be more likely to bleach the dial at the first attempt. But this would entail a greater element of risk of damage by loosening the dial feet. It is better to proceed in easy stages and gradually achieve full whiteness. Allow the dial to cool at least to the temperature of the acid before immersing. If immersed while hot it may warp and repeated hot plunges will increase the diameter by quenching the material while in an expanded condition.

When the surface is evenly white overall the contrasting patterns of engine-turning will not be easily distinguished by the naked eye. To improve the appearance hold the dial under running water and gently scratch-brush with a soft, brass, wire brush. The brushing must be very thoroughly done to brighten the surface equally into the corners.

Dry the surface with tissue paper and repeat the heating and immersion process. If the brushing and drying have been carefully done the surface will become white under the heat from the torch before red heat is reached. Rinse in the acid to verify the evenness of the whitening, wash under running water and dry with tissue paper. The surface will now have a silvery-white matt surface which will catch the light to emphasize the engine-turning. However, the surface is very delicate and must not be touched or rubbed. When the dial is finished it can be lacquered for protection.

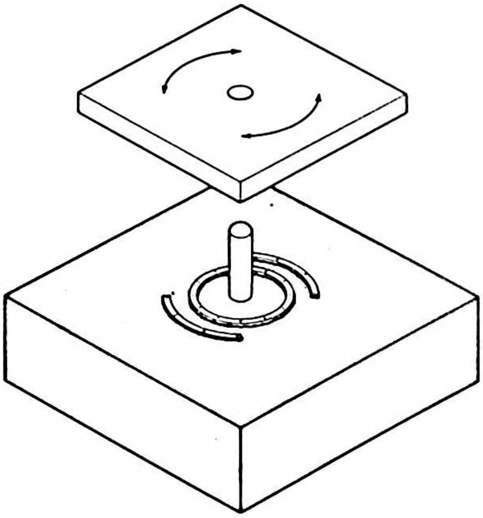
Chapter Rings

Brighten the chapter ring and signature cartouches with pumice powder mixed to a thick paste with water and applied with hard pith held in the compass, as shown in Fig 772. Finish cartouches with peg-wood cut to a chisel end and charged with the paste.



772 Finishing the chapter ring

Circular grain the seconds dial and sector scales with a piece of wood charged with paste and used as shown in Fig 773. Hold the pieces, spaced at the correct radius, with beeswax smeared on a cork block. Locate and rotate the wood on a pivot pin in the cork.

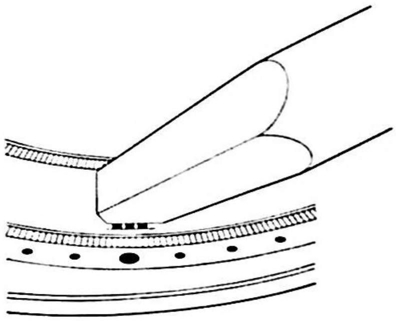


773 Finishing the seconds ring and sector scales

Finishing and Lacquering

Rinse the dial and pieces clean under running water. Dry by covering with tissue paper and gently pressing between the palms of the hands. This will soak up the excess water. The remaining dampness will air dry without leaving stains on the surface. If any paste remains in the corners after the rinsing it can be gently teased away with a fine camel-hair brush under running water. An ultrasonic bath of soapy water will remove all traces with ease.

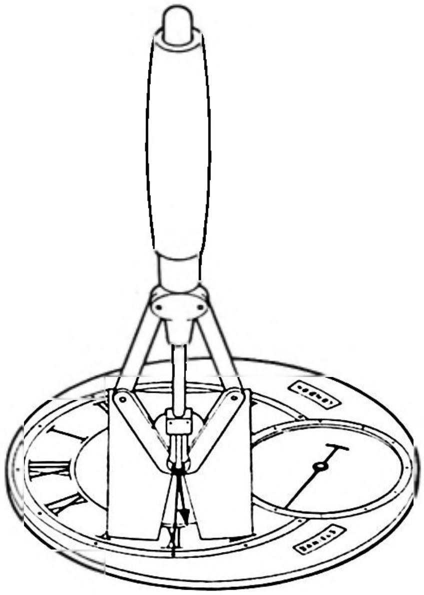
Fill the numerals and divisions with Indian ink. When dry apply a second layer. This will give the filling a rich black texture. When dry clean off any surplus from the surface with a stick cut to an angle across the grain. Cut the flat large enough to bridge the numerals and hold in level rubbing contact with the dial surface, as shown in Fig 774. Stubborn marks can be removed by moistening the flat of the stick.



774 Cleaning the numerals

Lacquer the dial and pieces with thin cellulose lacquer applied with a broad soft brush. To prevent the possibility of dust falling on the surface cover over while drying. Finally assemble the seconds ring and sector scales and the dial is ready for fitting.

Should it be necessary to remove the hands, protect the surface of the dial with paper, as in Fig 775, while levering off the hands. If this useful tool is not available use a pair of separate levers.



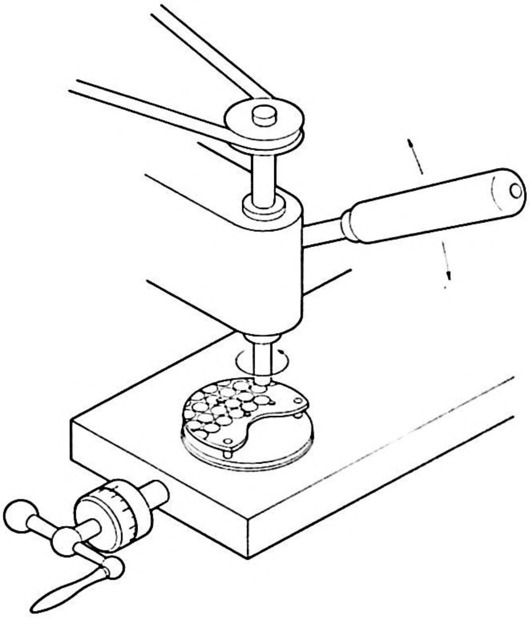
775 Protective paper for removing hands

Finishing Watch Plates

Watch plates are now usually made from brass or nickel. Early German watches were made from iron. They were followed by the French with brass plates, the brass being gilded to prevent discoloration. Swiss makers introduced nickel frames in the nineteenth century. The Swiss were much concerned with the sparkling appearance of their Geneva bar movements, to which they applied damascene decoration. Nickel does not readily oxidize and so the damascening will remain bright for many years. It is done mechanically with wood or ivory and abrasive paste.

Spotting

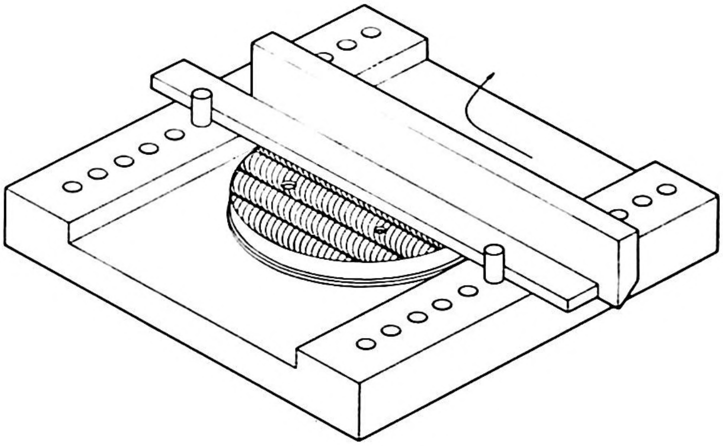
There are two basic methods. The first is shown in Fig **776**. The vertical quill is revolved with a belt or bow. The ivory rod gripped in the lower end may be solid or hollow. The plate *P* is covered with a wet pumice powder paste. The pattern is formed by bringing the revolving ivory rod into contact with the paste which will mark the surface of the plate with a whirl or ring depending on the form of the end of the rod. The plate is advanced at regular intervals. This process was used by the English chronometer makers who described it as 'spotting'.



776 Spotting machine

Graining

The second method, using a metal straight edge and a boxwood polisher, produces regular paths of curved grain. The work rests on a wooden board with holes along the edges, as in Fig **777**. The straight edge is located against pegs which are advanced along the board as the work proceeds. After each row of grain use a soft brush to re-apply wet pumice powder to the plate. If necessary the height of the work must be adjusted with packing pieces to ensure level contact with the polisher.



777 Damascening watch plates

Gilding

Brass plates will become tarnished if left unprotected. The application of a thin layer of gold will both protect the surface and improve the appearance. Traditionally the gold was dissolved in mercury and the resultant amalgam rubbed on to the brass to cover every part of the surface. The work was then heated over a charcoal fire to drive off the mercury and leave the gold thinly deposited over the surface. The fumes from the charcoal help to reduce oxidation. There is some danger to the health of the operator if the mercuric fumes are inhaled.

After cleaning and scratch-brushing, the surface will be a lustrous, matt, lemon-yellow colour which will resist stains and oxidation. The contrast of blue screws, polished steel and gilded plates is most pleasing and refined and superior to any other finish.

Electro-Gilding

Gilding by electro-deposition can produce the same finish and is cleaner and more convenient. The work is suspended in a solution of potassium cyanide containing dissolved gold. Also suspended in the solution is an anode plate. The solution is heated to about 80 °C. A direct current of about three volts will be required for a watch plate. The positive wire is applied to the anode while the negative current is passed through the watch plate.

If the solution is rich in gold salts the anode may be stainless steel and non-dissolvable. When large quantities of work are to be gilded a gold anode will prevent exhaustion of the solution. The current can be supplied by a battery while the gold salts for the solution are readily obtainable for mixing with water.

Jewellers' material suppliers can supply complete gilding sets ready for use. These have controls for varying solution temperature and current density by which means the colour can be varied.

Colour

Generally speaking lowering the temperature and current will produce a paler colour. But salts ready made up by a supplier may be constituted to produce a pink shade. This can only be changed by altering the constituents. The addition of a minute amount of silver solution will help produce a lemon-yellow colour. Advice on gilding solution is obtainable from manufacturers' workshop instruction sheets.

The surface of the metal must be prepared before gilding which will merely cover the surface without affecting the texture. Thus the finish obtained by the methods relating to Figs 776 and 777 will, after a light gilding, be unchanged except for colour. If the process is continued the pattern will remain but the surface will become increasingly dull.

Preparing the Surface

To produce the lustrous matt surface of mercurial gilding the watch plates must first be polished free of all scratches. Do this with wood polishers charged with polishing paste. All marks left by the flattening stone must be erased by the polishing.

Matt the surface with a fine, steel, wire mop used dry and revolved at not less than 3,000 rpm. Allow only the tip of the bristles at the edge of the brush to touch the work surface. Because only a very small area of the plate will be in contact with the bristles the work must be moved to and fro so that the brush can cover the whole surface. Turn the work through 90° and repeat the process. Each time the whole surface has been covered the work can be turned and the process repeated. In the early stages the surface will assume a soft sheen without obvious matting, such as is found on early English plates. Increased application of the brush will increase the matting which will eventually become very sharp and bright.

Some practice is needed to achieve a completely uniform surface. An excess of matting over engraving or raised edges will produce an exaggerated sharpness. If it is required to reduce the matting the surface must be repolished and the work started again. It is important that the brush bristles touch the surface only briefly and without dragging in contact.

After matting suspend each piece loosely on a copper wire. Rinse in degreasing agent and finally, briefly immerse in a bath of equal parts of sulphuric and nitric acid diluted with twenty parts of water. This bath will leave the surface chemically clean and ready for gilding. Rinse in warm water and place in the gilding bath. After gilding scratch-brush under running water with a gentle circular motion of the brush used in the hand. Dry in warm boxwood dust.

Cleaning and Oiling

Many months may pass between the completion of the first and last components of a watch movement. The plates will receive almost continuous attention throughout the movement's construction and some components will also need frequent handling, especially when their action is linked to components that are to be made later.

Inevitably the surface of brass components will become stained, and dirt will lodge in holes for bearings, steady-pins and screws. When starting to make each new component the plates and associated components should be washed clean to prevent the mating surfaces becoming marked during contact. This is simply and safely done with an ultrasonic bath of warm water and liquid soap. Put the pieces in a wire gauze basket and immerse for about one minute. Remove the basket from the solution and place it upon an absorbent surface to soak up the excess water. Finally, rinse in methylated spirits to remove all traces of water and dry in warm, boxwood dust.

Plates and other large pieces can be dried by placing them in a shallow tray of boxwood dust. It is safer to put small components in a sieve box. This comprises a cylinder of metal or cardboard about 70 mm in diameter and about 100 mm in length, with a lid at each end and a gauze division half way up inside. With the bottom lid in position, half fill the top half with boxwood dust. Put in the components to be dried and, with the top lid in position, invert the box to cover the components with the dust. After a few minutes invert the box again and gently shake it from side to side, tapping if necessary, to sieve the dust into the lower half of the box. This will leave the dry components in the upper half. Tip them into a tray and gently blow them with the bellows to remove any remaining dust.

This treatment will leave the pieces clean without causing any abrading or chemical action to the surfaces. If it is required to remove accumulated stains and oxydation add a little ammonia to the soapy water. This will quickly remove the stains and leave the surfaces chemically clean, but will also allow re-oxydation to occur more quickly. A better, although slower, method is to remove the stains with a soft brush charged with a mixture of soap, water and rouge. Afterwards rinse in warm water and dry as described.

When the watch is completed and ready for final assembly after gilding, it will be adequate simply to clean the components in an ultrasonic, soapy water bath. Any stains should first be removed by re-finishing the component part. After the soapy water has been absorbed, rinse in fresh, warm water and then in methylated spirits to absorb all traces of water. Finally, rinse in clean benzine and cover immediately with boxwood dust to avoid air drying which could cause water condensation on the surfaces.

If any dust should still cling to the components after drying it can be removed by gently blowing it away with the bellows, or brushed away with a soft, watercolour paint brush. Thoroughly clean all holes, and polish jewel holes with sharpened peg-wood. This is especially important for brass-bearing holes which would score the pivots if any trace of dirt were left in the holes. Polish pallet and locking stones with clean, freshly cut pith. Examine every surface for dirt and stains which must be completely removed before the components are assembled.

During assembly, lubricate the mainsprings with grease and the barrel and centre pivot holes with fine, clock oil. For the train and escapement pivots use watch oil. Modern synthetic oils are more stable in their consistency and lubricating qualities than the older, refined, natural oils which suffered viscous changes with age and temperature variations. Only a very little oil is necessary as the capillary action of the oil will hold it close in to the pivot on the inside surface of the jewel. It is only necessary to see a thin ring of oil surrounding the pivot on the upper surface within the oil sink. Where the jewel has an end-stone, place the oil at its centre. When fitted, the capillarity will centre the oil at the dome of the jewel.

Lastly, fit the movement, together with dial and hands, into the case and the watch is now ready for final rating.

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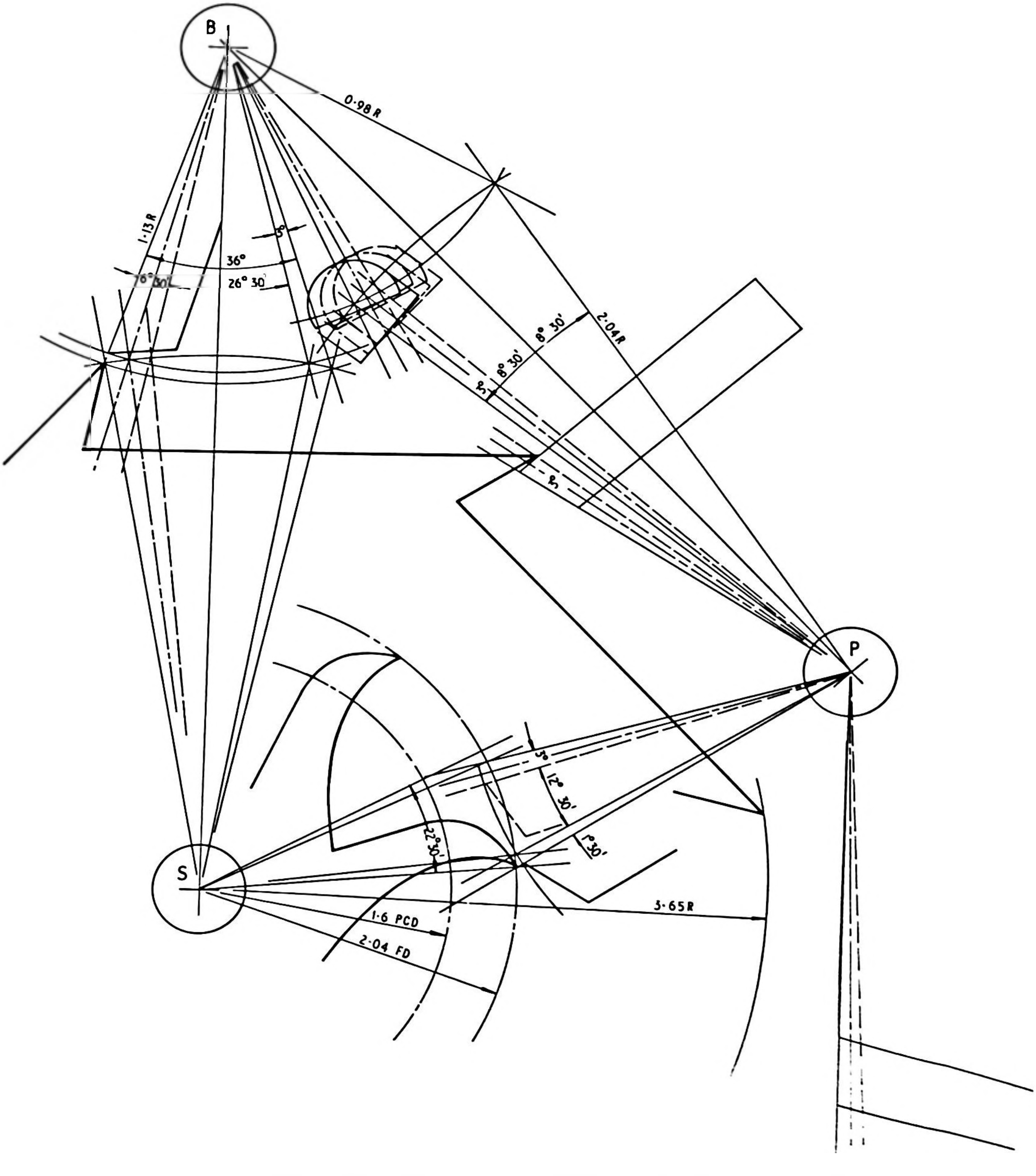
Jaquet, E., and Chapuis, A., *The Swiss Watch* (Berne, 1953)
Mercer, V., *John Arnold and Son* (London, 1972)

APPENDIX I


B
0·98 R
1·13 R
3°
36°
10°30'
26° 30'
2·04 R
8° 30'
8° 30'
3°
3°
P
S
3°
12° 30'
22° 30'
1° 30'
3·65 R
1·6 PCD
2·04 FD

Arrangement of extra flat co-axial escapement for balance angle of 36° and lever angle 17°

APPENDIX II

To Set Out the Independent Double-Wheel Escapement

If linear dimensions are to be taken, the drawing should be to a scale of at least 20:1. Mark off the centre distance of the balance to escape wheel. From centre *A* of the wheel draw the angles *CAO* and *DAO* of 10° each and the angle *EAC* of 4°. From centre *O* of the balance draw the angles *ROA* and *AON* of 18° for the 36° of escaping angle. From *D* mark off the additional tooth spaces *F*, *G* and *H* of 24° and the transfer drop angle *U* of 4° from *H*.

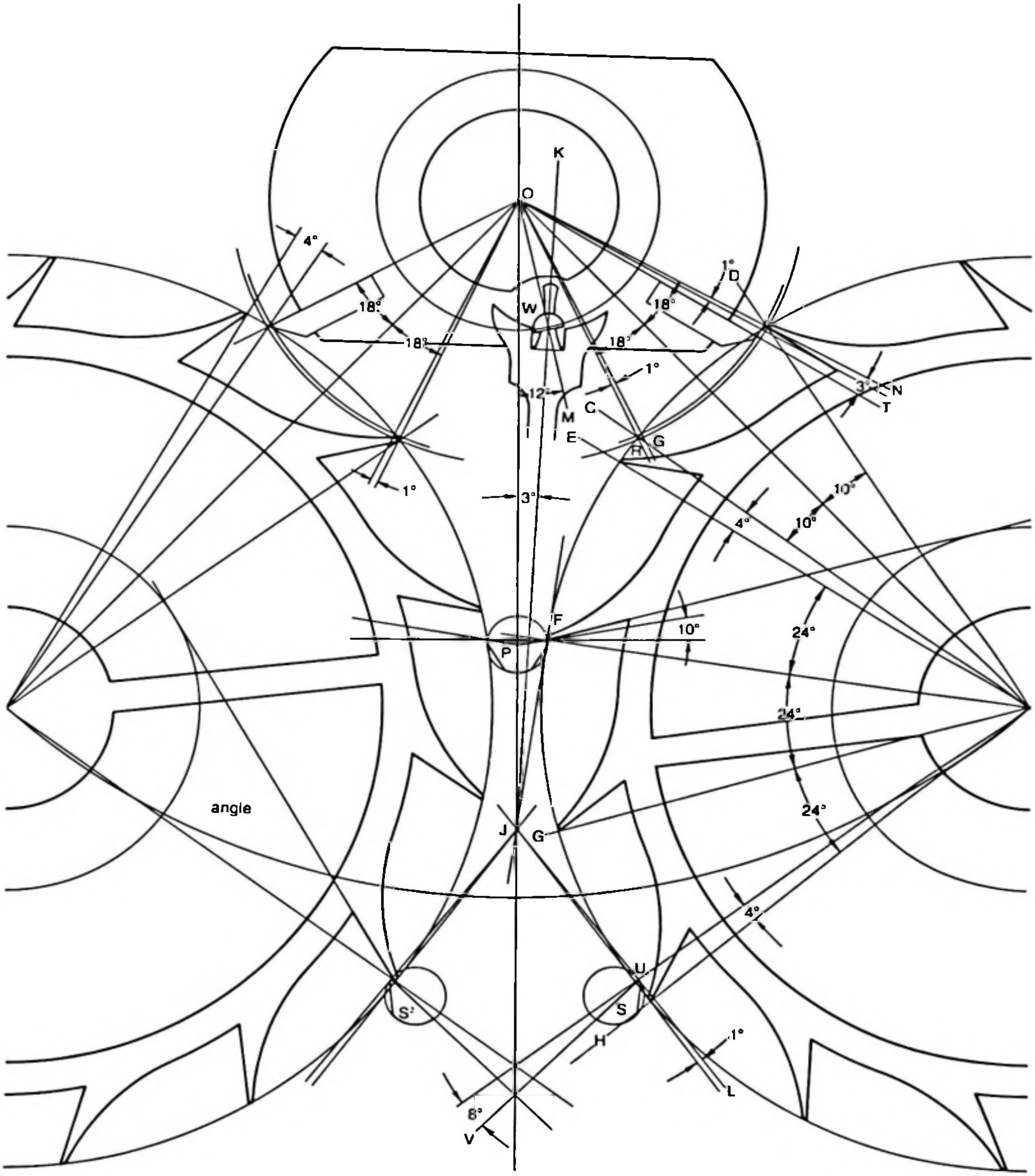
From *F* and *U* extend tangents to intersect at the lever pivot *J*. The line *JO* is the centre line of the escapement. Extend the locking point of tooth *F* to touch line *JO* at 10° of draw vertical to *JO*. Where the two lines meet, centre the circle for the principle locking stone *P*. From *J* draw *L* to pass 1° inside the circle of the tips of the wheel teeth. At the intersection of *U* and *L* raise *UV* at 8° of draw to *V*. Centre the secondary locking stone *S* on line *AU*. Draw the line *OT* at 3° to *ON* to indicate the face of the pallet at the moment of unlocking.

From *J* draw line *JK* for the lever unlocking angle of 3°. From *O* draw line *OM* at 12° of balance unlocking angle. The locking and unlocking angles are equal at 12° each side of the centre line and will be completed 16° before the completion of impulse. The impulse angle is 36°, minus the 3° of *TON* and of *ROG* leaving a total of 32°. At the intersection of *JK* and *OM* is the radius for the unlocking pin.

The impulse, locking and draw angles of wheel *P* are identical to those of wheel *A* and are constructed from angle *AOJ* and distance a depth of 1° and the transfer drop angle of 4° is approaching the circle for the radius of the impulse pallet.

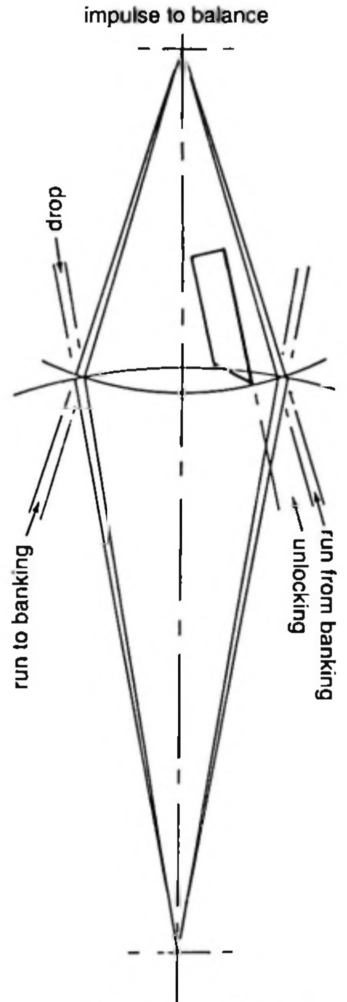
The details for the fork, roller pin, safety roller and guard pin are as described earlier for the lever escapement.

Independent double-wheel escapement unlocking and impulse angles


K
O
4°
1°
D
18°
W
18°
18°
18°
1°
3°
N
T
12°
M
C
E
R
G
1°
3°
10°
4°
10°
F
10°
P
24°
A
24°
angle
24°
J
G
4°
U
S²
S
H
1°
L
8°
V

Independent double-wheel escapement unlocking and impulse angles

APPENDIX III



1a Impulse to balance

To set out the extra-slim co-axial escapement

Set out the centres *B* & *S* at any convenient distance.

Draw the angle *ASC* of half a tooth space and the angle *DBE* for the escaping angle.

Draw arcs *F* & F^1 to define the wheel diameter and roller radius.

From C draw angle *GS* at 22.5° for the exit locking tooth.

From C draw angle *HS* at 90° for the entry locking tooth.

Draw tangents *VP* and *YP* to locate the pallet pivots.

Draw pallet centre line *BP*.

From *P* draw lever angles *PBK* & *PBL* and 2° locking *PVM*.

At the intersection of *PV* & *GS* draw the angle 14° of draw for the locking face.

On arc *WH*, at the required lever angle, draw *PN* and 2° locking *PO*.

Draw the entry locking face at 12° to *HO*.

At the intersection of *PL* & *J* draw roller pin *T*.

Complete the detail of lever for guard dart and safety roller.

Draw arc F^2 to allow 0.03 mm clearance of the impulse pallet.

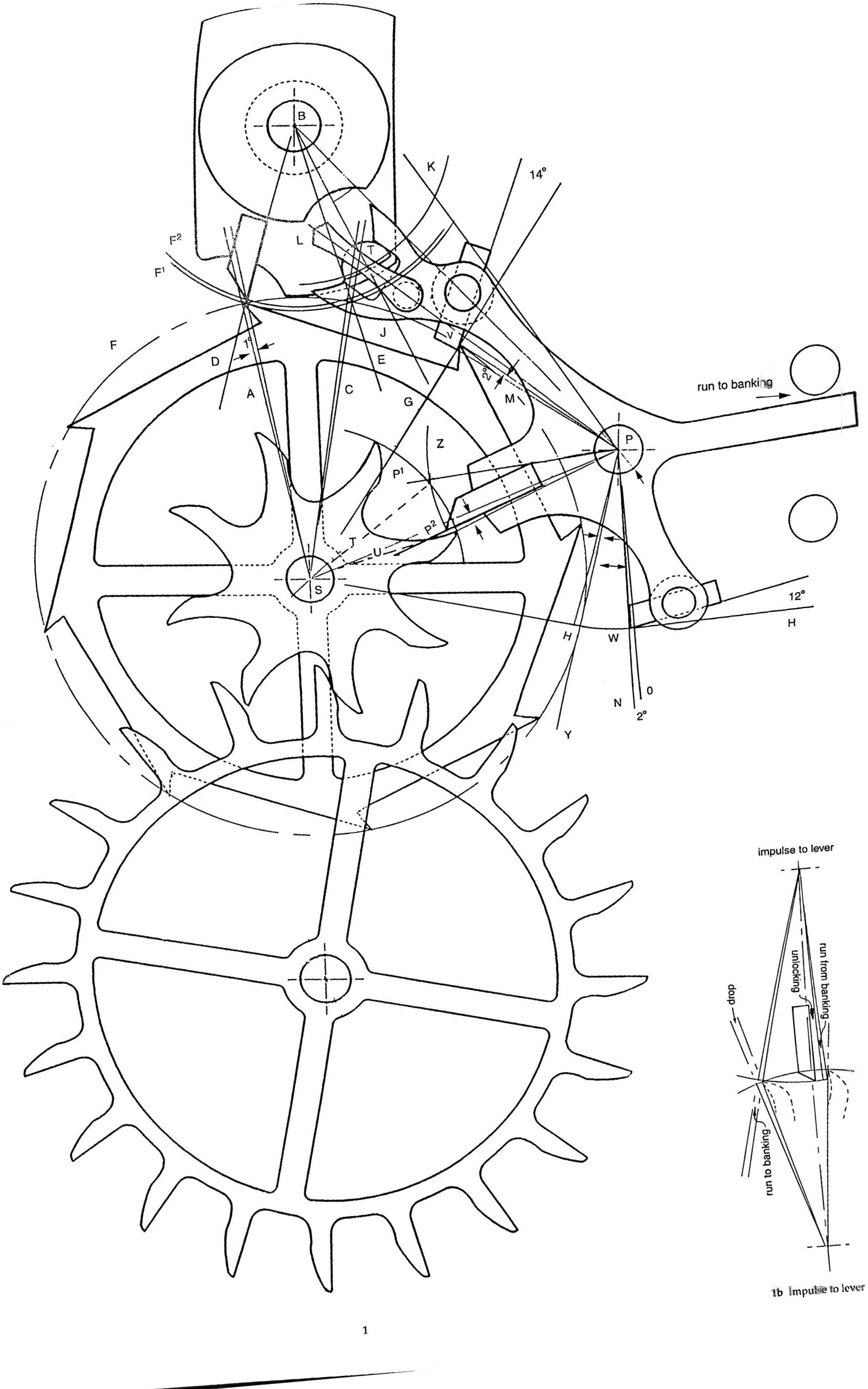
Draw lever angle P^1 & P^2 and pinion addendum angle *UST*.

Define the lever pallet length with arc Z allowing 1° drop at *P*& P^2.

To ensure safe intersection of the lever pallet with the pinion addendum the pallet is set at 4° before *PS*.

The dimensions of the components and their interrelated angles will depend on the centre distances, the numbers of teeth in the escape wheels and the chosen escaping and lever angles.

From a study of Fig 1 it can be seen that excessive locking depths, drops and clearances will cause a reduction in impulse angles. The areas indicated in Figs **1a** & **1b** must be given close attention to avoid possible loss of efficiency.


B
K
14°
F2
F1
L
T
F
J
V
D
1°
E
2°
A
C
G
M
run to banking
Z
P
P1
P2
T
U
S
12°
H
W
H
N
0
2°
Y
impulse to lever
run from banking
unlocking
drop
run to banking

1b Impulse to lever

1

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Italic numerals refer to pages on which drawings appear

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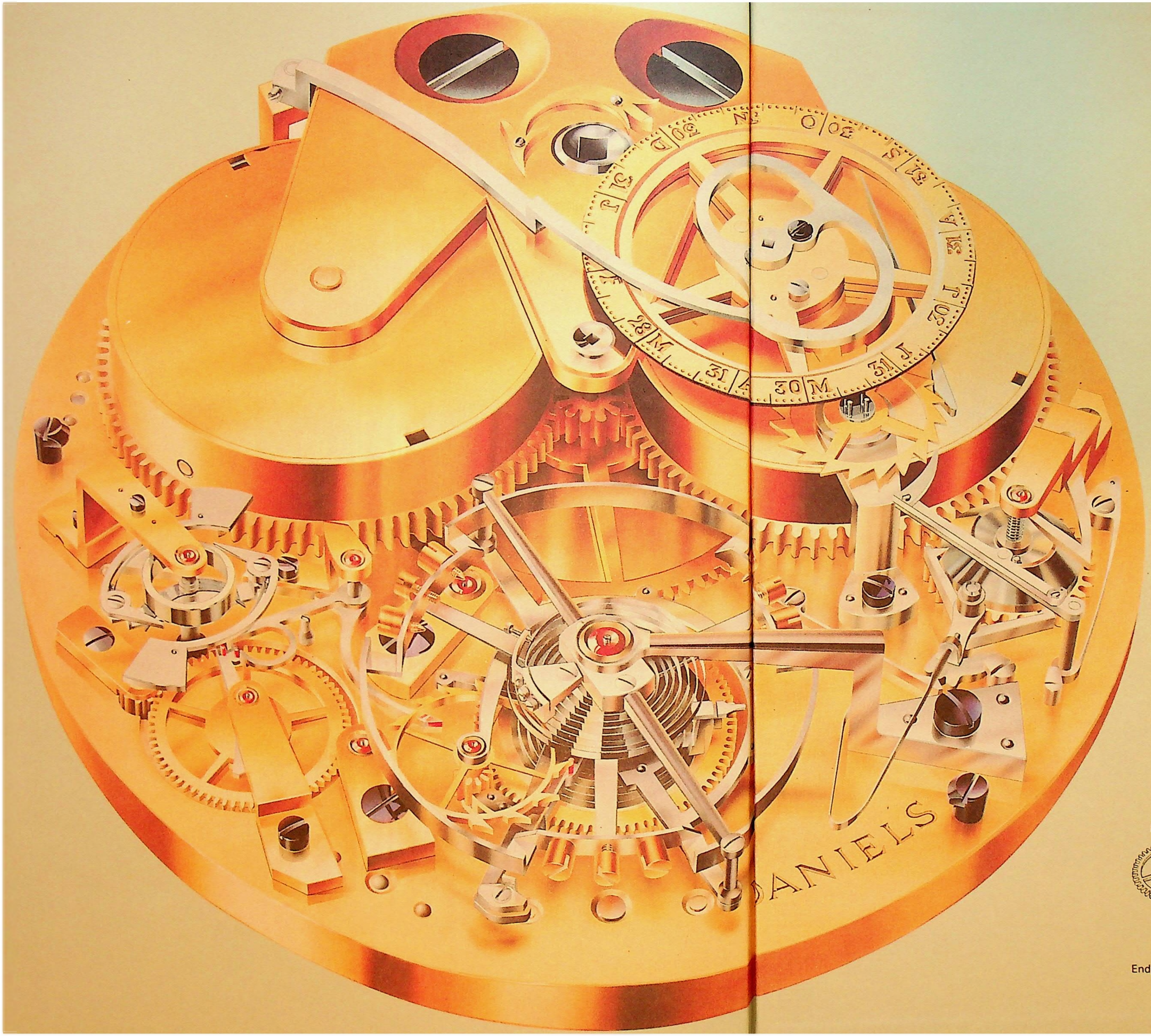

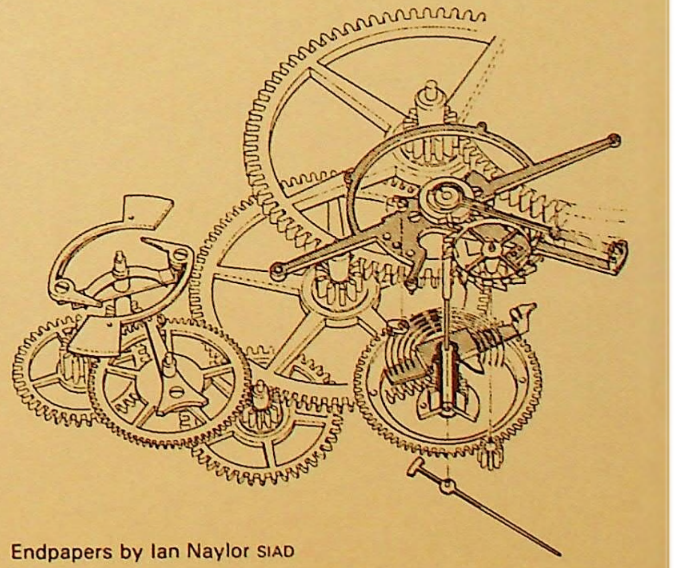

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